ONTARIO HIGH SCHOOL PHYSICAL GEOGRAPHY

REVISED EDITION

AUTHORIZED BY THE MINISTER OF EDUCATION FOR ONTARIO

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REVISED EDITION

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PREFACE

The Ontario High School Physical Geography is, in the main, a text-book of Physiography, with the addition of a sufficient description of the Solar System and of the Stars to acquaint the student with certain of the fundamental facts of Astronomy. Since, however, the study of Geography can be neither truly scientific nor educational unless it is humanistic in its aim, the intimate relation between Physiography and Political and Economic Geography has not been neglected. References will be found throughout the text to the influence exerted by physical conditions upon the life of man. In addition, the final chapter of the book consists of a series of problems specifically designed to illustrate the close relationship of Physical to Economic Geography. The questions are not intended to cover all possible geographical relationships; rather they are intended to give the teacher some very definite problems to solve in conjunction with his class, and at the same time to suggest the lines upon which further work of this very valuable type may be conducted.

The treatment of the material throughout is designed, as far as possible, to show the relation of effects to their causes, and no facts are given without explanation, with the exception of a few important principles of which the explanation is generally conceded to be much too difficult for the second year High School pupil. In such cases it has been deemed wise to state the principle involved as clearly and simply as possible, without burdening the pupil with a mass of detailed theory which would tax the powers of much more mature minds.

The laboratory method of teaching geography has been adopted wherever practicable throughout the book, in accordance with the best educational practice of the day. The Preliminary Experimental Work preceding the chapters has been carefully designed to elucidate the scientific principles essential for the proper understanding of actual geographical conditions. In this way Physical Geography has been closely correlated with its contributory sciences. Consequently, the book serves, not only as a self-sufficient text-book in Physical Geography, but also as a good introduction to the more detailed scientific studies of the succeeding years of High School work.

The questions which follow many of the chapters are suggestive rather than exhaustive. They are intended to show the alert teacher one of the most satisfactory ways in which the work of a chapter may be reviewed through the application of its principles.

The authors were assisted in their work by Dr. D. E. Hamilton of the Ontario College of Education. They were also aided by Prof. C. A. Chant of the University of Toronto, to whom they are indebted in general for much valuable advice in connection with the chapters on the Solar System and the Stars.

Toronto.
July 26th, 1923

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PHYSICAL GEOGRAPHY

CHAPTER I

INTRODUCTORY

1. The subject-matter of Geography.—Geography is that science which deals with the earth as the home of man. It paints a wonderful picture of the whole world, with its teeming peoples, its varied climes, its towering mountains, its fertile plains, its rushing rivers, its placid lakes, its stormy seas. It even reaches out beyond the confines of our world and adds to its canvas the whole vast universe, of which our world is but one tiny atom. Yet always is man the central figure of the picture; for sea and land and sky and stars and sun are of interest to the student of geography only by virtue of their effect upon man and upon man's life.

But geography is not content with merely presenting to us even so vast and magnificent a picture as this. It must also explain the causes and trace the effects of the various natural phenomena with which it deals. It is not enough merely to know that the rainfall in southern Ontario is much heavier than that in southern Alberta; we must discover the reasons for such phenomena and examine closely their effects, if we are to derive full benefit from our geographical studies. In studying geography, therefore, we are studying the earth with a view to obtaining a knowledge of natural phenomena, their distributions, causes, and consequences, especially in so far as such knowledge enables us to understand how and why the conditions of human life are thereby affected.

When we ask why the sky is blue, or what causes the gorgeous colours of a flaming sunset, or for what reasons our western prairies are the finest wheat lands in the world, or why population is usually densest on flood-plains or along sea-coasts, or any one of thousands of similar questions, we look to geographical science for an answer.

One of the first essentials to a knowledge of this most important science is an acquaintance with the distribution of natural phenomena. We must know, for example, the distribution of land and water, of mountains and plains, of lakes and rivers, of winds and rain, of vegetation and animals, of peoples, countries, and products. The Public School Course in Geography deals, in the main, with such distributions. Through it much has been learned about the different peoples of the world, their countries, and the natural conditions under which they live and work. Something has been learned, too, of the causes and the effects of the natural phenomena which largely determine their ways of living. Yet much remains untouched. It is, therefore, the purpose of this book to enlarge the knowledge that has been already gained, by a more intensive study of certain of the most important phases of geographical science.

2. The relationship of geography to other sciences.—The science of geography is largely dependent upon other branches of science, making use of much of the knowledge won by them, and applying for its own purposes many of the devices originated by scientists working toward very different ends. When we study the earth in relationship to the rest of the solar system, we draw upon astronomy for our facts. When we measure temperature by means of a thermometer, or air pressure by means of a barometer, we are using instruments based upon physical laws. Chemistry aids the geographer in

many ways, as, for instance, in determining the constituents of the air or of soils. Geology, which deals with the earth's crust, helps us in the study of land forms, even when we are viewing them from a purely geographical standpoint. Botany, the science which deals with plant life, and zoology, which takes animal life for its province, also contribute to geographical knowledge. In many ways these sciences all play their part in helping the geographer to solve the problems of his particular field of study.

Geography, in turn, makes its contribution to other branches of knowledge. It is of great value, for instance, in helping to explain the course of historical and political events. If we inquire why Britain has become the greatest maritime power of all time, or if we wonder why Africa has lagged so far behind the other continents in developing a high civilization, or why Montreal, Toronto, and Winnipeg have grown to be the largest cities in Canada, it is the science of geography that aids in giving us an adequate answer.

3. The divisions of geographical science.— The science of geography may be divided, for the sake of clearness of description and convenience of study, into three fairly distinct fields. Physical Geography deals with the natural features of the earth and the agencies that modify them. This branch of the subject is of the highest importance, as it gives the key to a real understanding of many of the most powerful natural influences affecting the life of man. The greater part of this book falls within this division. If we make man's position and activities upon the earth the chief feature of our study, and deal largely with countries and peoples, products and trade, we are studying Political and Commercial Geography. This phase of the subject has already been dealt with in your previous work in

geography. When we confine ourselves to a consideration of the earth as a planet and examine its relationship to the various heavenly bodies, especially to the sun, we are studying Astronomical, or Mathematical Geography. This is the most difficult phase of the subject and for that reason its consideration is reserved for the latter part of this book.

Whether, however, we are studying Physical Geography, Political and Commercial Geography, or Mathematical Geography, our ultimate aim is always the same. All geographical study aims at an explanation of all those natural phenomena which together form man's environment and which determine, to a very large extent, the conditions of his life.

4. The Earth — general view.— You already know from your study of elementary geography that the earth's surface consists of land and water, over which there is a layer of air. You know, too, that all the oceans are connected, so that the water forms a continuous layer, which, however, is interrupted in places by protruding land. Our knowledge of the interior of the earth is much less than that of its surface or of the air above it; but the majority of scientists are now agreed that the interior of the earth is a solid mass, rigid as steel.

We may say, then, that the earth consists of an unknown nucleus and three envelopes. The inner envelope, called the earth's crust, is composed of rocks and soil and is of unknown thickness. The middle envelope is composed of water. Although it is called an envelope, it is not a complete one, as it covers only about three-quarters of the surface of the earth. The projecting parts of the earth's crust form the continents and islands, while the layer of water forms the oceans and other bodies of water. The outer envelope is gaseous. It is called the atmosphere. It forms a complete layer at least two

hundred miles thick. The atmosphere should not be regarded as a separate envelope surrounding the earth, but rather as the outer envelope or layer of the earth itself, for it is as much a part of the earth as are the rocks. As the name, earth, however, is usually applied to the three inner denser parts, it will be used in that sense in this text-book. Picture the earth as a sphere eight feet in diameter; then the water would be represented by a layer nowhere more than one-twelfth of an inch in depth, and the atmosphere by a layer about three and one-half inches in thickness. These envelopes will be described in the following order: first, the atmosphere, then, the layer of water, and, finally, the earth's crust.

The teacher should keep in mind that the purpose of the course in Physical Geography is not only to impart knowledge, but also to create in the pupil a desire to observe the features and phenomena of the world around him, and to reflect upon them. To help in attaining this purpose, the following suggestions in Methodology will be found useful:

1. The study of each topic should begin by a discussion of facts, relative to the topic, which come within the scope of the pupils' ordinary experience, or by field work carried on during an excursion conducted by the teacher.

2. Experimental work should then be done to explain and amplify the observations and conclusions.

3. The text-book should then be read as a means of further elucidating the topic under consideration.

4. The cycle should be completed by the pupil returning to the study of the outside world with powers of observation strengthened by increased knowledge and made keener by curiosity.

CHAPTER II

THE NATURE AND COMPOSITION OF THE ATMOSPHERE

Preliminary Experimental Work

(*1*) *To prove that air has weight.*—

Fit a Florence flask, preferably round-bottomed, with a one-holed stopper, in which is a short piece of glass tubing with a short rubber tube on the end. Put half an inch of water in the flask, reinsert the stopper tightly, and boil the water for five minutes, allowing the steam to escape through the rubber tube. Take the flame away, and, at the same instant, close the mouth of the rubber tube with a pinch-cock, releasing it once or twice during the first few seconds to allow the excess steam to escape. Weigh the flask, stopper, tubes, and pinch-cock. What sound is heard? Explain the cause of it. Has the weight changed? Why?

(*2*) *To prove that gases diffuse.*—

By means of an atomizer spray some strong perfume into the air at one end of the class-room. Let each pupil indicate the moment when the odour is perceptible. In this way note the rate at which the perfume traverses the room. While this experiment is being performed, all doors, windows, and ventilators should be closed, to prevent draughts.

(*3*) *To show the buoyancy of air.*—

Inflate a toy balloon with coal gas, natural gas, or hydrogen; tie the neck tightly with fine silk thread, and release the balloon. In what direction does it move?

In what direction would it move if the air were exhausted from the room?

(4) *To illustrate the density of substances.*—

Find the dimensions of a rectangular block of wood. Calculate its volume. Weigh the block. Calculate the weight of one cubic centimetre of the wood. Weigh a beaker. Pour into it an exact volume of water measured in a graduate, and weigh. Find the weight of one cubic centimetre of water. What is the relation between the weight of a cubic centimetre of wood and that of a cubic centimetre of water?

(5) *To prepare and test oxygen.*—

Into a hard-glass test-tube put a heaping teaspoonful of a mixture of three parts of potassium chlorate and one part of manganese dioxide. Heat the mixture carefully. Light one end of a piece of string and lower the glowing tip into the test-tube. What difference is there between the action of a glowing string in air and in the gas coming off from the mixture in the test-tube?

(6) *To prepare nitrogen.*—

Smear the inside of a test-tube or a gas-bottle with moistened iron filings and place it mouth down in water. Leave in a warm place for several days, and note the changes. Make the levels inside and outside the bottles the same. Cover the mouth tightly with a cover-glass, remove the bottle, and place it upright on the table. After inserting a burning splint into the bottle, and observing the result, measure the volume of water in the bottle, and also the total volume of the bottle. What fraction of the volume of the air was absorbed by the filings? How does the gas not absorbed by filings differ from air?

(7) *To prepare carbon dioxide.*—

Put some marble chips into a Florence flask, fitted with

a stopper, thistle-tube, and delivery tube, as in Figure 1. Through the thistle-tube add water to cover the chips, then hydrocloric acid till the bubbles come freely. Pass

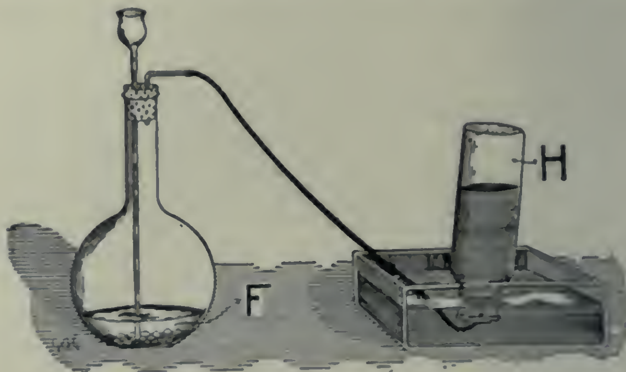


Fig. 1.—Preparation of carbon dioxide
F. Flask containing baking-soda and vinegar
H. Bottle in which carbon dioxide is collected

through lime-water the gas that comes from the delivery tube. What is the effect of this gas upon the lime-water?

Collect over water two jars of this gas. After removing them from the water, hold one with the mouth up, the other with the mouth down, for two minutes. Then put a little lime-water in each jar and shake. Which jar contains the greater quantity of carbon dioxide? Is this gas heavier or lighter than air?

(8) *To illustrate* (*a*) *reflection of light*, (*b*) *refraction of light*, (*c*) *the spectrum.*—

Let a beam of sunlight enter a darkened room through a narrow slit in a blind. Make its path visible by putting chalk-dust in the air. Trace its path.

(*a*) Place an inclined mirror in its path. What effect has the mirror on the direction of the beam of light?

(*b*) By means of a mirror reflect the beam obliquely into a rectangular vessel of water. What change of direction takes place as the beam enters the water?

(*c*) Place in the path of the beam a triangular glass prism and receive on a screen the beam after it has passed through the prism. Notice the effect of the prism on the direction, the width, and the colour of the beam. Name the colours in the order in which they appear on the screen. What colour is nearest to the original path of the beam? What one is farthest away?

(9) *To show the effect of small particles on light.*—

Arrange apparatus as in Figure 2. The glass vessel contains a clear solution of sodium thiosulphate. A beam of light *A* from the lantern *E* passes through the water *L* and is received as a bright circle of light in the mirror *K*. The mirror is so inclined that the

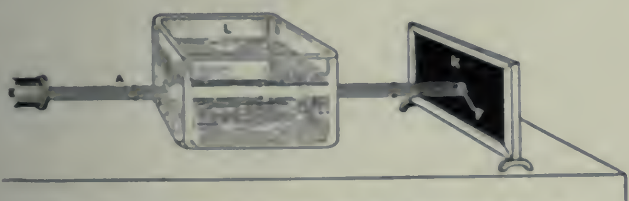


Fig. 2.—Apparatus to illustrate the blue colour of the sky

bright circle of light *F* can be observed by the pupils. When the room is darkened, observe the colours of the beam of light in the water and of the bright circle of light in the mirror. Then pour a few cubic centimetres of sulphuric acid into the solution and stir the mixture thoroughly. Observe the changes in colour of the beam of light as it passes through the liquid, and also the changes in colour of the bright circle in the mirror.

(*10*) *To show the radiant energy of the sun.*—

Place a radiometer in bright sunlight. In which direction does it turn? Which side of each vane warms more quickly? What effect has this warmed surface upon the adjacent air? On which side does the air exert the greater pressure? What is the source of the energy that causes the rotation of the vane?

The Nature and Composition of the Atmosphere

5. The importance of the atmosphere.— The air we breathe, just as the land beneath our feet, is such a commonplace of our existence that ordinarily we scarcely give it a thought, much less realize fully how essential, in fact, how all-important is the atmosphere to life upon the earth. We know, of course, that all plants and animals require air in order to live; without it even the fish deep down beneath the surface of the ocean would die. But that is not all the story. If it were not for the protecting blanket of the atmosphere covering the surface of the earth, the heat of the sun's rays would be so intense by day that life would be impossible, while by night the heat would radiate so rapidly into space from the earth's surface that soon after sunset the cold would be more biting than that of an Arctic winter. There would be no clouds, no rain, no snow; no running water carving the land into beautiful hills and valleys; no winds to drive before them the white-crested waves; no sound to break the utter silence of the horrible, dreary waste of lifeless, motionless matter which then our world would be.

6. The height of the atmosphere.—The air, like all gases, has weight and is drawn toward the earth, but it also tends to diffuse outward so as to occupy empty space. While the atmosphere has probably no definite outer limiting boundary, it becomes so diffuse beyond a height

of two hundred miles as to be difficult to detect. Men in balloons have ascended more than eight miles, and balloons without occupants about twenty-four; therefore even at these heights the air must be dense enough to buoy up considerable weights. The phenomenon of twilight indicates that the air extends to a height of at least forty-five miles; for this phenomenon is due to the air at that elevation reflecting the light from the sun below the horizon. The phenomena of meteors prove that the atmosphere extends to a still greater height. Such bodies become visible only when the friction due to their swift motion through the air makes them red-hot. It is possible from the data obtained by careful observation of such meteors to calculate their altitude, and it has thus been found that at an elevation of one hundred miles or more the air still exerts enough friction on a meteor to make it glow. The aurora borealis, or northern lights, is supposed to be caused by the action of electricity on very rarefied air. Since the aurora is seen frequently at a height of over two hundred miles, it is probable that air in a very rarefied state extends to that great altitude. Nevertheless, almost half of the total mass of air lies below a height of three and a half miles, and more than three-fourths of it below seven miles.

7. The composition of air.—The air, except at great altitudes, is composed chiefly of three gases—oxygen, nitrogen, and argon. About four-fifths of the volume of the air is nitrogen, almost one-fifth is oxygen, and slightly less than one per cent is argon. Besides these components, there is always present a small amount of carbon dioxide and an amount of water vapour that varies greatly at different times and places. There are also some minor components, such as ammonia, nitric acid, and ozone. The composition of the air varies little

near the surface of the earth. At great altitudes, the heavier gases, such as oxygen, nitrogen, and argon, are largely replaced by the lighter gases, such as hydrogen and helium, which are absent from the lower air.

Figure 3 illustrates in a general way the variation in composition with height.

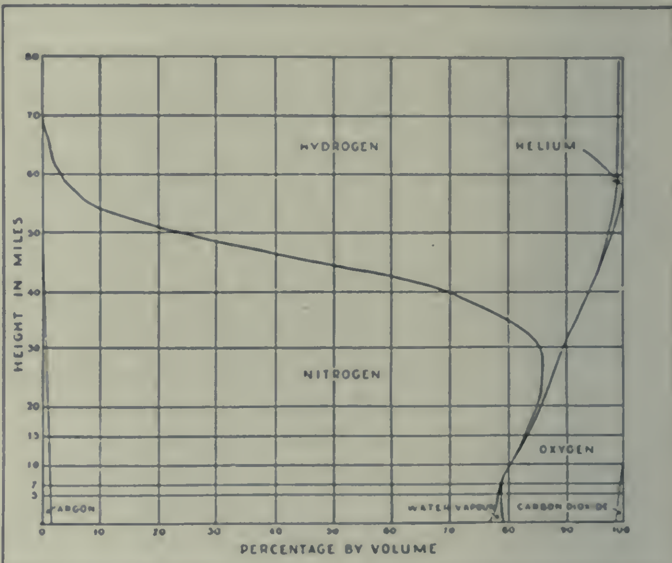


Fig. 3.—Diagram showing the composition of the air

The Components of the Air

8. Oxygen.—Oxygen is the most important component of the air. All plants and animals require it in order to maintain life. Were it not for the oxygen in the air, fire, in the ordinary sense of the word, would be impossible, as its presence is necessary for ordinary combustion. Oxygen promotes the decay of plants and animals and thus prevents their remains from

accumulating on the land and in the water. Again, the presence of oxygen is necessary for the decomposition of rocks and for their conversion into soil. It might be thought that all these processes, continually using vast quantities of oxygen, would lead to a diminution of the amount of this gas in the air. The loss is balanced, however, by the addition of oxygen to the air as a result of other processes. All green plants in the presence of sunlight give off oxygen; and since the amount of vegetation upon the earth's surface is enormous, the quantity of oxygen added in this way to the air is also very great. A small quantity of oxygen is also added to the air from the earth's crust by changes taking place in certain rocks and through volcanic vents.

9. Nitrogen.—An atmosphere of pure, undiluted oxygen would destroy animal life just as surely, though not as quickly, as an atmosphere lacking it entirely. Pure oxygen, if taken into our lungs, would stimulate our bodies to such a degree that we should almost literally "burn up" in a short time. The nitrogen in the air, while having no direct effect upon animal life, serves very effectually to dilute the oxygen to such an extent that it does not over-stimulate. The nitrogen in the air has also little direct effect upon plant life, for, although all plants require food containing nitrogen, only a few of the lowest type can use the free nitrogen of the air for this purpose. Atmospheric nitrogen must first be converted by various agents into new products, before it can be utilized by the higher plants.

10. Carbon dioxide.—Although carbon dioxide is present in the air in very small quantities, constituting, as it does, only three parts in ten thousand, it plays an important role. Almost all vegetable life depends upon it for food and extracts it continually from the air for this purpose. At the same time, as respiration, com-

bustion, and decay are continually adding large quantities of it to the air, the quantity of this gas in the air does not change much from time to time. Moreover, as we shall see later (Sec. 22), the carbon dioxide serves as a screen by day to protect the earth from the full intensity of the sun's rays, and as a blanket by night to prevent the heat which has been absorbed by the earth's surface from escaping into space.

11. Water vapour.—Water vapour is confined entirely to the lower layers of the atmosphere (Fig. 3) and is very variable in quantity. Nevertheless, it is an important component of the air, for without it there could be no clouds, rain, snow, or dew. Like carbon dioxide (Sec. 22), it serves both as a screen to cut off the sun's rays and as a blanket to prevent the radiation of heat from the surface of the earth.

12. Dust.—Dust may be regarded as an impurity of the air, yet it is present in all parts of the lower atmosphere. Dust particles are not numerous above the sea or above snow-capped mountain tops, but in the air of cities there are hundreds of thousands of such particles in a single cubic centimetre. Dust is composed partly of rock particles raised from the dry earth by the wind, partly of meteoric dust, partly of the pollen and spores of plants, partly of the salt from evaporated sea-spray, and partly of smoke. The last is the chief source of dust. The number of particles poured into the air from chimneys is beyond calculation. It has been estimated that one puff of smoke from a cigarette contains four thousand million dust particles.

It might be supposed that the dust in the air is nothing but a nuisance, but such is not the case. If, by some miracle, every particle of dust were suddenly removed from the atmosphere, we would notice great changes. The blue sky would appear much darker than it is at

present, because air particles only would then scatter the light; the gorgeous colours of sunrise and sunset would be absent, and many other phenomena that give beauty and variety to the sky would be missing. Dust particles also play a great part in the formation of clouds and rain-drops, as the moisture in clouds condenses about them. Almost every rain-drop has a dust particle as a nucleus.

There is in the dust of the air much organic matter, composed largely of the spores of bacteria and other fungi. While some of the bacteria cause disease, most of them perform useful functions. Certain ones give the characteristic flavours to cheese, butter, and other important food products. Others convert the nitrogen of the air into substances that can be utilized as food by the higher plants, while others, by promoting decay, clear away plant and animal refuse from land and water. In the spring and summer there is much pollen dust in the air. This is of great importance, as the seeds of many of our most essential food-plants are produced through wind fertilization.

The Colours of the Sky

13. The nature of the sun's light.— When a pebble is dropped into water, a series of waves moves out from the point at which it strikes the water. These waves move forward in every direction in circles of increasing size until they strike the shore. The distance between two successive wave-crests is called the length of the wave. When a handful of pebbles of various sizes is thrown into the water, each pebble produces a series of waves. Some of the pebbles, however, cause longer and higher waves than others. Consequently, there are waves of varying lengths moving forward simultaneously in circles.

Filling all space there is supposed to be a medium

called ether, and through this medium waves spread out from the sun very much as the waves spread out from the pebbles dropped into water. The waves from the sun differ, however, from those on the water in two important respects, since they move forward, not in circles, but in spheres, and since they are not of few wave-lengths, but of very many, ranging from very long to exceedingly short ones.

When water-waves strike the beach, they often have sufficient force to move sand and pebbles for a considerable distance higher up the shore. Thus the water-wave can overcome resistance and perform work. When a person or an object overcomes resistance, we say that he or it has *energy*. A moving stone, a current of electricity, and a boiler full of steam are all able to overcome resistance, and, therefore, possess energy.

Although the waves from the sun cannot directly move pebbles or similar objects, they can produce motion in certain bodies and can be converted into light, heat, and

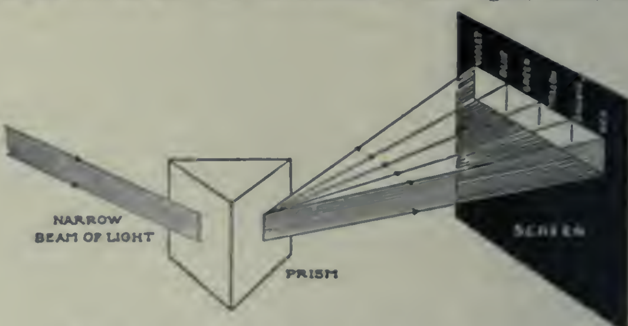


Fig. 4.—The breaking of white light into its colours

other forms of energy. The waves from the sun we call *radiations*, and their energy, *radiant energy*.

If certain of these radiations enter the eye, they produce a sensation of colour. If a narrow beam of

sunlight is passed through a triangular glass prism (Fig. 4), a remarkable change takes place. The beam bends from the line in which it has been travelling, and some parts of it bend more than others. As a result, the beam becomes wider, and if the widened beam is received on a screen, it forms a coloured band of light. This band, called a *spectrum*, is composed of the colours of the rainbow—red, orange, yellow, green, blue, and violet. The glass triangle has separated the radiations by bending or refracting some more than others. The coloured band (Fig. 4) shows that the least refracted waves produce the colour red, those most refracted produce violet. The waves producing the red light are the longest, those producing the violet the shortest, and the length of the waves producing the other colours are in the order in which these colours stand in the spectrum. Hence it is clear that, the longer the waves, the less they are refracted in passing through the prism.

Fig. 5.—Section of earth to show that a horizontal ray passes through a greater thickness of air than does a vertical ray

14. The blue of the sky.—If the colour of the sky is observed during the day when the air is clear and cloudless and the sun is high, it will be noticed that it is deep blue overhead, but becomes whiter toward the horizon and also toward the sun. It was at one time thought that the blue of the sky was due to the

colour of the gases that compose the air. But it can be easily shown that the air is not blue in colour. The depth of air in a line drawn horizontally from a given place to the outer limit of the atmosphere is much greater than in a line drawn to the zenith (Fig. 5), and if the air itself is blue, the colour of the sky near the horizon should be a deeper blue than near the zenith. But the reverse of this is true.

Water-waves are affected in one of two ways when they meet obstacles. If the obstacle is small as compared with the wave, the wave flows around the obstacle and continues on its way almost unaffected. If the obstacle is somewhat larger than the wave, the wave, instead of passing on, may be reflected and scattered. The waves of the sun are similarly affected by dust particles in the air. The shorter waves (green, blue, and violet) are scattered for the most part, and only a small portion passes onward, while the longer waves (red, orange, and yellow) continue their course in almost full strength. If the sun's light is passed through a vessel of water containing very fine particles in suspension (Fig. 2), the water, when viewed from the side, appears light blue, owing to the scattering of these rays by the particles, while the source of light, when viewed through the water, appears yellow, orange, or red, according to the extent of the scattering of the shorter waves. Similarly, the short waves of the sunlight are scattered by the dust particles in the air, and by the particles of the air themselves, and these scattered waves make the sky appear blue.

15. The sunset colours. — Let us now recall the appearance of the sky as the sun is setting on a cloudless afternoon. As the sun approaches the horizon, the western sky glows with brilliant colours, which persist after the sun has set and only fade away in the twilight. Near the sun, at the centre of the sunset arch, the colour of the

sky is silver, while a short distance from the centre the colour is a glowing yellow. Farther still from the centre the colour is a delicate pink or purple rose, which gradually merges into the blue of the sky. The arch flattens out and is greatly prolonged north and south near the horizon. As the twilight advances, the colours grow fainter and become more suffused with red, and the margins of any clouds in the vicinity are edged with the same brilliant tint. The eastern horizon shows an arch of the same colours as those in the west, but much fainter. As the sun sinks, the eastern arch rises, but as it does so, becomes very faint and soon disappears. Since the sun loses its brilliancy as it approaches the horizon, the eye can then look at it directly. It takes on the same series of colours as the adjacent sky and finally sets as a crimson sphere.

Figure 5 shows that, in order to reach the earth, the rays of sunlight must penetrate a greater depth of air when the sun is near the horizon than when it is high in the sky. In fact, the rays from the setting sun penetrate a stratum of the air thirty-five times as deep as that penetrated by the vertical rays from the sun at noon. Moreover, a great part of the stratum of air through which the horizontal rays pass is near the surface of the earth, and, consequently, contains many more dust particles than does the purer, upper air. Since the light coming from the setting sun and the adjacent parts of the sky has its short waves almost completely scattered by this thick stratum of dusty air, only the long waves (chiefly red, orange, and yellow) reach the eye. Consequently, the sun and the sky in its vicinity show these brilliant colours at sunset.

16. The transparency of the air.—The transparency of the air varies greatly both in different localities and from day to day in the same locality. In the cities the

transparency is much less than in the country, while it is greatest over the ocean and in the polar regions. It has been shown within recent years that the transparency of the air depends upon the size and the number of the dust particles between the eye and the object, and upon the humidity of the air. Although the number of dust particles in the air may be the same on two successive days, the range of visibility may be markedly different. The drier the air, the greater is the range. This fact is explained as follows: All objects, including dust particles, are surrounded by thin films of water. When the air is humid, the film of water is thicker than when the air is dry. Consequently, each dust particle in the air is a greater impediment to the light in humid weather than in dry, and thus the transparency of the air is lessened.

Practical Exercises

The composition of the air at different altitudes.—After studying Figure 3 answer the following questions: What are the five components of the air at the surface of the earth? Which is the first component to disappear as the altitude increases? At what altitude does water vapour disappear from the air? What, therefore, is the greatest altitude at which clouds will usually be found? Leaving out of consideration the water vapour, the amount of which is very variable, to what altitude does the composition of the air remain almost constant? State the change in the composition of the air between the altitude of seven and that of twenty miles. State at what altitude each component appears and at what altitude it disappears. What changes in the composition of the air are to be observed between the surface of the earth and an altitude of eighty miles?

The colours of the sky.—When the sun is high above the horizon on a clear and cloudless day, observe the

colours of the sky and record answers to the following questions: What is the colour of the greater part of the sky? What is the colour of the sun? What is the colour of the sky near the horizon? What is the colour of the sky near the sun? On an evening when the sky is cloudless, observe from an elevated position the sunset colours. Notice the different colours the sun assumes as it approaches the horizon. Describe the different colours of the part of the sky near the sun. What is the shape and what the size of the brilliantly coloured region around the setting sun? How far north and south does the brilliantly coloured region near the sun extend? Observe the changes in the sunset colours until they fade in the darkness. Describe the sunset colours near the eastern horizon. In a similar manner describe the sunrise colours.

Sometimes a ring is seen around the sun or the moon. When such a ring is present, notice whether it is partly coloured, whether the colour is on the outside or on the inside of the ring, what distance the ring is from the sun or the moon, and whether, at the time the ring is seen, the sky is clear, hazy, or cloudy.

QUESTIONS AND PROBLEMS

1. Why does the sun look reddish when the air is smoky?

2. Since dust particles are solids, they are much heavier than the air. Why are they able to float about in the air?

3. If a thoroughly dusted room is left closed for a long time, when it is opened the furniture is found covered with dust. Explain the source of the dust.

4. Why does a mountain climber require to breathe faster the higher he ascends?

5. After the eruption of Krakatoa had hurled large quantities of volcanic dust into the upper air, brilliant sunsets were observed for many months all around the world. Explain this phenomenon.

CHAPTER III

THE HEATING OF THE ATMOSPHERE

Preliminary Experimental Work

(1) *To compare the capacity for heat of land with that of water.* —

(*a*) Into one beaker put 250 g. of dry earth and into another 250 g. of water and raise the temperature of each to the boiling-point. For this purpose the beaker containing the earth should be covered with a piece of cardboard and left partially immersed in boiling water until the desired temperature is reached. The beaker of water can be directly heated to the boiling-point by a Bunsen burner or an alcohol lamp. While the two beakers are being heated, measure into each of two large tumblers 250 c.c. of water at the temperature of the room. Pour the hot earth into one tumbler, the boiling water into the other, stir both, and note the temperatures to which the mixtures rise. Which mixture reaches the higher temperature? Which gave out the more heat in cooling, the hot earth or the hot water? Does the land or the water give out more heat as it cools during the autumn and the winter?

(*b*) Into one beaker put 250 g. of dry earth, into another 250 g. of water, and allow both to stand until they reach the temperature of the room. To each add 250 c.c. of boiling water and stir. Note the highest temperature to which each mixture rises. Which reaches the higher temperature? Did both receive the same amount of heat? Which requires more heat to raise its temperature one degree? Which probably warms more quickly in the spring, land or water?

(2) *To compare the rates of heating and of cooling of land and of water.*—

Place side by side on a table two similar beakers, one containing a quantity of fine, dry soil, and the other an equal quantity of water. These substances should be at the same temperature. By means of a mirror, cause the rays of a projection lantern or of the sun to be reflected on the surface of the soil and water. Take the temperature at the surface of each substance. Which grows warm the more quickly?

Apply the results of the above experiment to explain why the sand on a beach feels colder than the water in the early morning, whereas in the afternoon the sand feels warmer than the water.

(3) *To illustrate absorption and reflection of radiations.*—

Hold the bulb of a thermometer in the smoke over the flame of burning turpentine until it becomes covered with soot. When this thermometer has cooled to the temperature of the room, hold it and another thermometer, which has not been so treated, in bright sunlight. Read the temperature of each every minute until the mercury ceases to rise. Which absorbs heat more rapidly, the bright bulb or the black one? Which absorbs heat more readily, a smooth, bright surface or a dull, black surface?

17. Importance of temperature.—We have already learned from the study of elementary geography that the atmosphere is not heated to an even temperature all over the earth. As we pass from the torrid zone southward or northward, the average temperature of the atmosphere becomes lower as we approach either pole. As the average temperature changes, so also plant and animal life changes; we do not find tropical palms in the Arctic regions or polar bears in the torrid zone. We may say, therefore, that the distribution of plants and

animals on the earth is partly determined by the distribution of temperatures, since each species of plant and animal is able to live only in localities where the range of temperature is suited to its needs. The occupations of mankind, too, are determined to some extent by conditions of temperature. The Eskimo, for instance, is forced to hunt or to fish for his daily food, as the average temperature of the far north is too low to permit the growth of food-plants. Again, all motions of the air, with their accompanying phenomena of winds, clouds, rain, and snow, are caused primarily by changes of temperature. Obviously, a knowledge of the heating of the atmosphere is of the first importance to the student of geography.

18. The thermometer.—The mercury thermometer is made in the following way: A bulb is blown at one end of a piece of thick-walled glass tubing of small, uniform

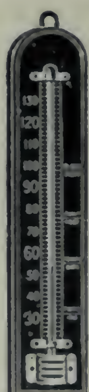


Fig. 6 *a*.—An ordinary Fahrenheit thermometer

Fig. 6 *b*.—A maximum thermometer (as used in the Meteorological Service)

Fig. 6 *c*.—A minimum thermometer (as used in the Meteorological Service)

bore. Bulb and tube are filled with mercury at a temperature slightly above the highest temperature for which the thermometer is to be used, and the tube is sealed in a hot flame. As the mercury cools, it contracts

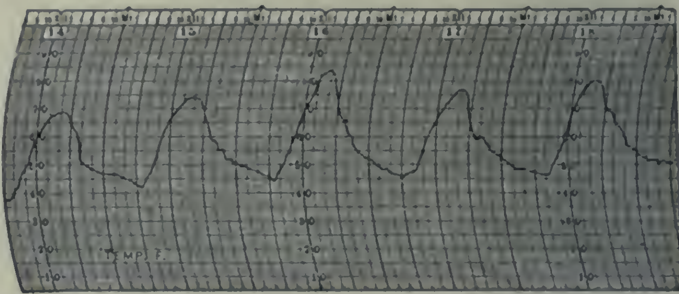
and falls away from the top of the tube, leaving a vacuum above it. Alcohol may be substituted for mercury. Graduations showing the temperature are placed on the bore of the tube or on a metallic scale behind the tube. The Fahrenheit scale is generally used in measuring the temperature of the air. On this scale the melting-point of ice is 32° and the boiling-point of water 212° (Fig. 6*a*).

Various special thermometers are also used for measuring and recording the temperature of the air. The most important of these are the minimum and maximum thermometers (Figs. 6*b* and 6*c*). If maximum and minimum thermometers are placed out of doors for a period of time, the former registers the highest temperature the air has reached during that time, while the latter registers the lowest temperature. By the use of the minimum thermometer the weather office is able to

Fig. 7.—A thermograph

learn the lowest temperature reached during a very cold night, and by means of the maximum thermometer it ascertains the highest temperature reached on a very hot summer's day.

Another instrument used for measuring and recording temperature is the *thermograph.* This records the temperature continuously on a sheet of paper by means of a pen. The paper is moved forward steadily by



Courtesy of The Macmillan Co.

Fig. 8.—Thermograph record, showing typical daily variation of temperature, Oct. 14-18

clock-work. Figure 7 is an illustration of a thermograph, and Figure 8 is an illustration of a thermograph record for several days.

19. Sources of heat.—The heat that warms the air comes almost entirely from three sources, namely, the interior of the earth, the sun, and the other heavenly bodies. Volcanic and other phenomena indicate that the interior of the earth is very hot, but, on account of the thick outer layer of non-conducting rocks, this heat reaches the surface of the earth only to a slight extent, and hence plays little part in heating the atmosphere. Since the heat received from the interior of the earth is as great at the poles as at the equator, the temperature at these two points would be nearly equal, if the earth's interior heat were the main factor in the heating of the atmosphere. The stars and some of the planets supply a still smaller amount of heat.

The heat received from the sun is so much greater than that received from all other sources that the latter

may be neglected entirely in studying the heating of the atmosphere. It has been calculated that only $\frac{1}{2,000,000,000}$ of the sun's radiated heat ever reaches our earth, yet even this small fraction of solar heat could melt annually a layer of ice covering the earth's surface to a depth of 141 feet. When we remember, however, that the sun is many times larger than our earth—325 earths could be placed around its equator like a string of beads—and that this great mass is extremely hot, with a probable temperature of 10,000°F., we need not wonder that the effect of the sun upon our earth is so great.

Heat, like light (Sec. 13), is a form of radiant energy. Practically all radiations are converted into heat when they strike a dull, dark body. If, however, they strike a light-coloured or bright surface, very little of their energy is converted into heat, as the greater part rebounds from such a surface and passes back into space. When the radiations are converted into heat, we say that they are *absorbed;* when they rebound, we say that they are *reflected.*

Radiations pass out not only from the sun, but also from all warm bodies. Short radiations, however, are emitted from intensely hot bodies only. The bodies of animals, for instance, emit long radiations, while incandescent lamps, glowing coals, and molten metals give off short radiations.

Both long and short radiations pass readily through pure air. Carbon dioxide, water vapour, and, especially, dust particles, absorb radiations to a certain extent. Consequently, air containing these components in large proportions is directly warmed by the radiations.

Short radiations pass readily through glass, but long radiations rebound from its surface. Thus the short radiations from the sun pass through the glass covering a hotbed and warm the earth within. The long radiations

from the warm earth, however, rebound from the glass and cannot escape. Consequently, the heat is retained within the hotbed.

The number of solar radiations reaching any part of the earth's surface depends on several factors: (*a*) The more nearly vertical the rays of the sun, the more intense are the radiations. From Figure 9 it can be seen that

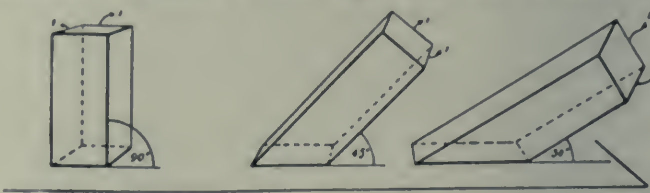


Fig. 9.—Showing how the same number of the sun's rays cover different areas, according to the angle at which they strike the surface. The cross section of each represents one square inch, but the vertical rays cover the smallest area; those striking at 45°, a greater area; and those at 30° an area still greater.

oblique rays are spread over a greater area than an equal number of vertical rays, and that the more obliquely rays strike the surface, the greater becomes the area over which they are spread. The greater the area over which a certain number of rays are spread, the less intensely will that area be heated. (*b*) The longer the time the sun shines on a surface, the more heat that surface absorbs. Hence the northern hemisphere of the earth accumulates more heat during the long days of June than during the short days of December. (*c*) The nearer the sun is to the earth, the more intense are the radiations. As the sun is farthest from the earth on July 1st, and nearest on January 1st, the earth receives about seven per cent more heat on the latter day than on the former. This is the least important by far of the three factors.

20. The heating of the land.—Land is heated much more quickly by the sun than is either air or water.

When the sun's radiations strike the earth, they are almost entirely converted into heat, not more than five per cent of them being reflected. These radiations are absorbed by a thin outer layer of earth, and, as the earth is a poor conductor, the heat at its surface is transferred to its deeper layers very slowly. Moreover, it takes little heat to raise the temperature of earth through one degree, compared with that required to raise the temperature of water to the same extent. On account of this effective absorption, slow conduction, and low capacity for heat, the surface of the earth warms up very quickly. As good absorbers are good radiators, the earth at night readily radiates its heat and rapidly cools.

21. The heating of the water.—The action of the sun's rays on bodies of water is very different from their action on masses of land. Over forty per cent of the solar radiations are reflected back into space from the surface of water, and, accordingly, have no heating effect on it. The unreflected radiations are not all absorbed at the surface, as some of them penetrate to considerable depths. In this way they distribute their heat through a thick layer of water, and, consequently, do not increase the temperature of any part of it very rapidly. Again, it requires a greater quantity of heat to raise the temperature of a mass of water one degree than to raise the temperature of an equal mass of any other substance one degree. There is usually much more evaporation from a water surface than from a land surface, and, as heat is required to evaporate liquids, the surface from which the evaporation takes place is cooled. This may readily be proved by placing a few drops of ether on the back of your hand. Unlike earth, water is constantly in motion. Thus the warm water is continually being mixed with the cold, and the temperature of the different parts is equalized. As a consequence of all these factors,

the water does not become warm nearly as rapidly as the land. While the temperature of the surface of the land may rise through many degrees during a single hot day, the temperature of the surface of the water of a near-by lake may not rise through more than a single degree.

22. The heating of the air.—As was stated in Section 19, the air absorbs some heat from the direct solar radiations. Carbon dioxide and water vapour absorb a small amount of heat, and dust particles still more. As the greater portion of these components of the atmosphere are in the lower air, the direct heating by the solar radiations is most effective close to the earth's surface. Nevertheless, if the sky is cloudless, the solar radiations reach the earth not greatly diminished in strength. Consequently, the air must receive the greater portion of its heat from the warm earth and water in contact with its lower surface. Heat passes from the warm earth or water into the adjacent air; this heated air may rise or be blown forward, distributing its heat to cooler air.

Range of Temperature

23. Daily range.—The following are the temperatures taken every hour in Toronto on a typical summer day in June:

TABLE 1

	a.m.											noon	p.m.											
Hour......	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Temp. F...	51	49	48	46	45	47	57	52	62	64	74	76	77	78	79	78	78	77	73	67	60	57	55	53

It will be noticed that the minimum temperature was reached about sunrise, that after sunrise the temperature increased steadily until about two or three o'clock in the afternoon, when a maximum was reached, and that

then the temperature began to drop slowly. After sunset it dropped much more rapidly for a few hours, and then continued to drop more slowly until the following sunrise. To understand the cause of this daily variation, two facts must be kept in mind. The sun is warming the air during the period of daylight only, while the air, on the other hand, is radiating heat into space throughout the whole twenty-four hours of the day. In the early morning the rays of the sun are nearly parallel to the surface of the earth and have to pass through a great thickness of the lower air, in which there is much dust. Therefore they do not warm the earth greatly. Hence the temperature of the lower air increases but slowly for some time after sunrise. Toward noon the rays become more nearly vertical and pass through a thinner layer of air, hence the heating effect increases and reaches a maximum at noon. For some time after noon, however, the temperature still rises. This is due to the fact that the amount of heat received from the sun, although not so great as at noon, is still greater than the amount of heat lost by radiation. At about three o'clock the amount of heat which is being received from the sun just balances the amount which is being lost by radiation.

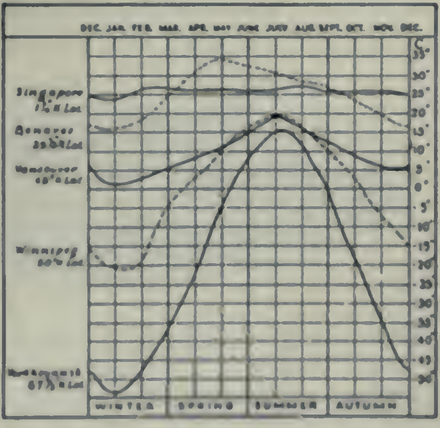
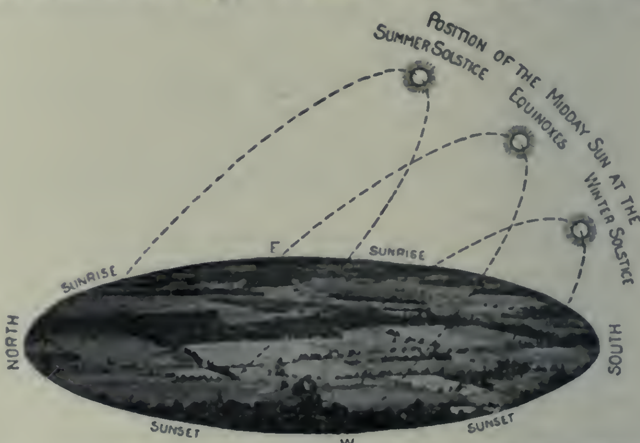


Fig. 10 —Graphical representation of the change in temperature in five cities. Benares is in India, Verkhoyansk in northern Siberia.

After that hour the amount of heat received from the setting sun steadily decreases. The amount lost by radiation decreases also, but more slowly. Therefore the air begins to cool and continues to do so until the sun again rises.

24. Seasonal change.—There is a steady change of temperature throughout the year. Figure 10 shows the annual range of five cities. Each, except Benares, has its highest temperature during July and August and its lowest temperature during December and January. In general, this range of temperature marks the seasons. The warmest season is called summer, the coldest, winter; so far as temperature is concerned, spring and autumn are transitional stages between the warm and the cold



Courtesy of D. Appleton and Company

Fig. 11.—Course of the sun and relative length of its diurnal arc at different seasons of the year; for latitude 45° north, observer at centre of picture.

seasons. The difference in the seasons is more marked in high latitudes than near the equator. Singapore, within a degree or two of the equator, can scarcely be said to have seasons, so far as a change of temperature is

concerned, while Winnipeg, and Verkhoyansk in northern Siberia, have a very pronounced difference between summer and winter.

Two factors determine the seasons. In summer the sun's rays are more nearly vertical than in winter, and so have a greater warming effect. Again, during the summer the days are much longer and the nights much shorter than during the winter. Figure 11 illustrates the facts just stated. The following table gives approximately the number of hours of sunlight for the first day of each month in the city of Toronto:

TABLE 2

Jan	Feb	Mar	Apr	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
h. [illegible]	h. 9.53	h. 11.11	h. 12.46	h. 14.12	h. 15.15	h. 15.26	h. 14.36	h. 13.13	h. 11.43	h. 10.14	h. 9.08

This table shows that on January 1st the sun shines for less than nine hours, while on July 1st it shines for more than fifteen hours. As on July 1st the rays are also much more vertical, the amount of heat received on that day must be much greater than that received on January 1st.

At the equator the sun shines for twelve hours a day throughout the year, hence the only factor that changes is the obliquity of the sun's rays, and this is never great. Accordingly, there is little difference of temperature between summer and winter in the torrid zone. As the latitude increases, the obliquity of the sun's rays becomes more and more pronounced in winter, while at the same time the difference between the length of the winter and the summer day increases; therefore the difference between the temperatures of summer and winter becomes greater. The extreme condition is reached at the poles, where for six months of the year there is continuous sunlight, and for the other six there is no direct sunlight whatever.

The Distribution of Heat

25. The vertical distribution of heat.—The air near the surface of the earth is the warmest, and there is a steady decrease in temperature as one ascends. This, at first sight, seems remarkable; for it is well known that warm air ascends, and the cooler upper air settles down. Hence it might be inferred that the cool air would be at the bottom and the warm air at the top, as is always the case in a room. The explanation of the decrease in the temperature of the air with increase of altitude depends on an important property of gases, which can be readily demonstrated. When a bicycle tire is being pumped up, the bottom of the barrel of the pump and the rubber tube connecting the pump with the tire become quite warm. This is not due to friction, as can readily be shown by disconnecting the pump from the tire and repeating the same motions as before. Again, if a thermometer is held at the opening of the valve of a tire, and the compressed air is allowed to escape, the temperature of the expanding air decreases. These two phenomena illustrate the following important law regarding the expansion and the compression of gases. All gases, when they are compressed, become warmer, and, when they expand, become cooler. Consequently, when air is compressed in the lower part of a bicycle pump and in the rubber connector, both are heated by the warm compressed air within. When the valve of the tire is opened and the compressed air is allowed to expand, it again becomes cool. As warm air rises, the pressure of the surrounding air upon the ascending current diminishes. Consequently, ascending air, which is under a diminishing pressure, steadily expands and becomes cooler. For every thousand feet of ascent its temperature decreases 3°F. Accordingly, though air may be warm when it begins to ascend, it rapidly becomes cooler as it reaches

greater altitudes. This is one reason for the fact that the greater the altitude the lower is the temperature. When the surface temperature is 46°F., at a height of

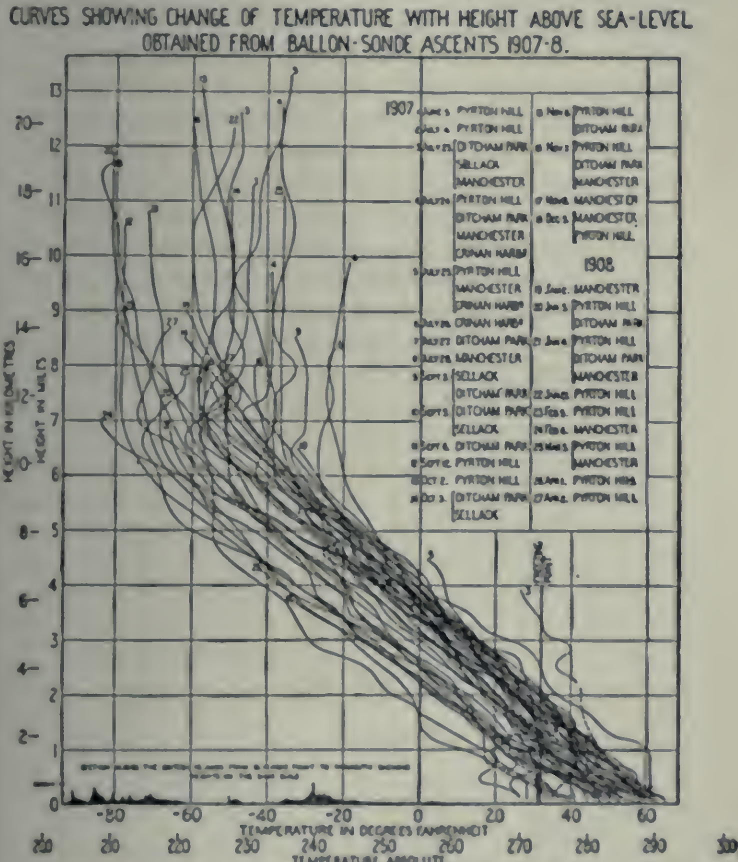


Fig. 12

one and a half miles the temperature is at the freezing-point, while at an altitude of six miles the temperature is about 56°F. below zero.

Within recent years the exploration of the upper air has been stimulated by the advances that have been made in aerial navigation. Much information has been obtained by a study of the records obtained from kites and balloons (equipped with self-recording thermometers and barometers) which have reached great altitudes.

The change of temperature with altitude can best be shown by a graph. Figure 12 is such a graph, showing the change in temperature recorded by twenty-seven sounding balloons sent up from different parts of England during 1907-8. It will be noticed from these graphs that the atmosphere can be divided into three layers: (*a*) a lower layer, extending to a height of about two miles, in which the change of temperature is very irregular; (*b*) a middle layer, which begins immediately above (*a*) and

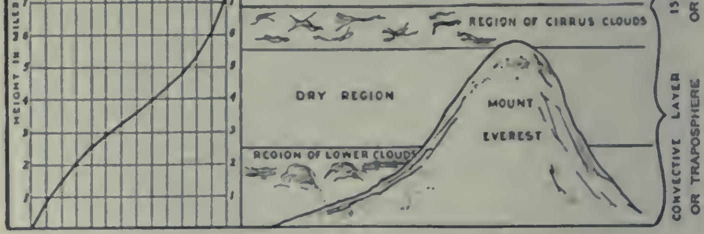


Fig. 13.—Represents the two layers of the air, the convective and the isothermal layer, with the most common positions of the clouds. Mount Everest—the highest mountain of the world—is represented for comparison with the height of the different layers. To the left the temperature of the air at different heights is represented graphically.

extends to an average height of seven miles above the earth's surface, and in which there is a steady and rapid fall of temperature; (*c*) an upper layer, in which the temperature, instead of continuing to fall with an increase of

altitude, remains stationary or even rises slightly. This upper part is called the *isothermal layer*, because it has the same temperature at different levels. Although sounding balloons have penetrated a considerable distance into this layer, it is not known to what height it extends. It is believed now that there is little or no diffusion between the isothermal layer and the lower layers of the atmosphere, and that the former floats on the latter much like a layer of oil on water.

The dense clouds are all formed in the lower layer, while the delicate, feathery, cirrus clouds (Sec. 35) are formed near the boundary between the middle and upper layers. Figure 13 illustrates these facts.

26. The surface distribution of heat.— The daily temperatures of numerous places in most parts of the world have been recorded for many years, and the average, or mean, temperatures of these places have been calculated from these records. If the mean temperatures for the day, or the month, or the year, for each place are entered on a map, and lines are drawn through all places having the same temperature, such lines are called *isotherms* or *isothermal lines*. Lines are usually drawn to show differences of five or ten degrees of temperature. A map of a district with such isotherms drawn on it is called an isothermal map. Such a map presents to the eye a clear picture of the temperatures of a district. Figure 14 is a map of the world showing the annual isotherms. Figures 15 and 16 show the isotherms of the world for January and July, respectively.

The map of annual isotherms shows that the lines run generally from east to west like the parallels of latitude, that the highest temperatures are near the equator, and that the lines are much more regular in the southern than in the northern hemisphere. The latter feature is due to the fact that the southern hemisphere contains only

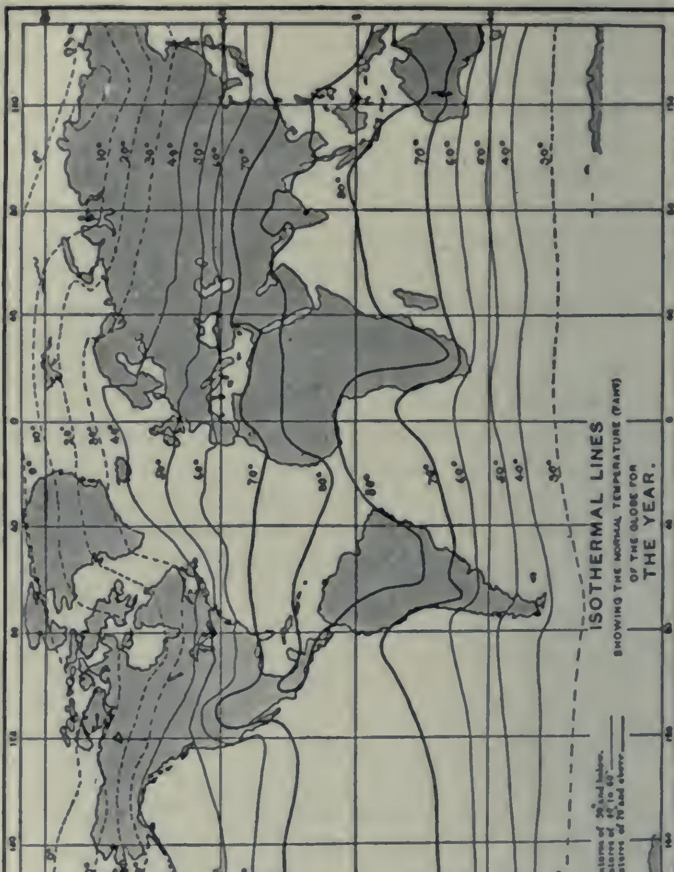


Fig. 14

Courtesy of The Macmillan Co.

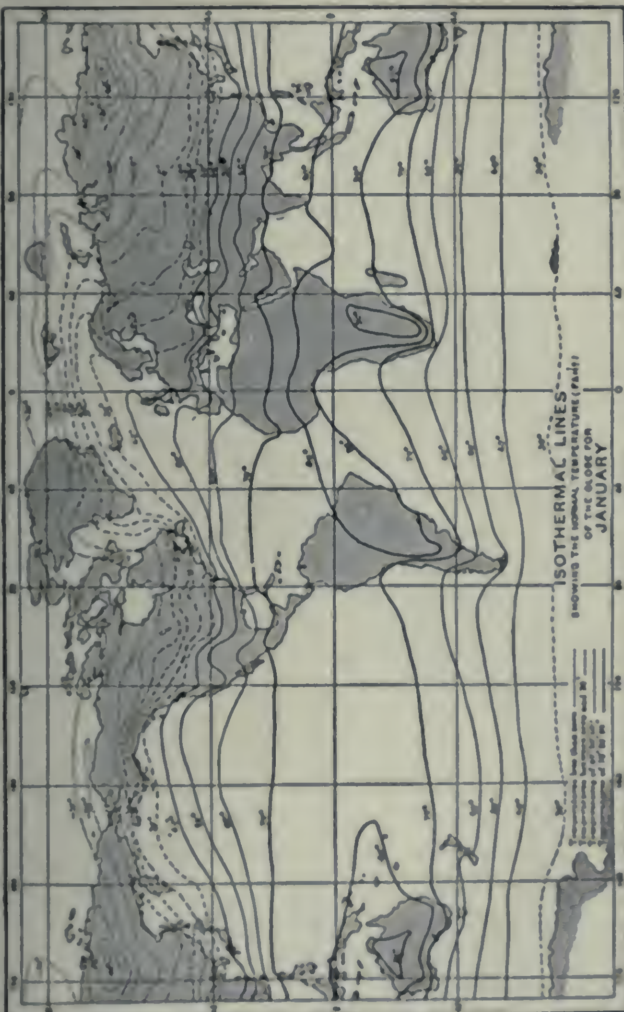


Fig. 15

Courtesy of The Macmillan Co.

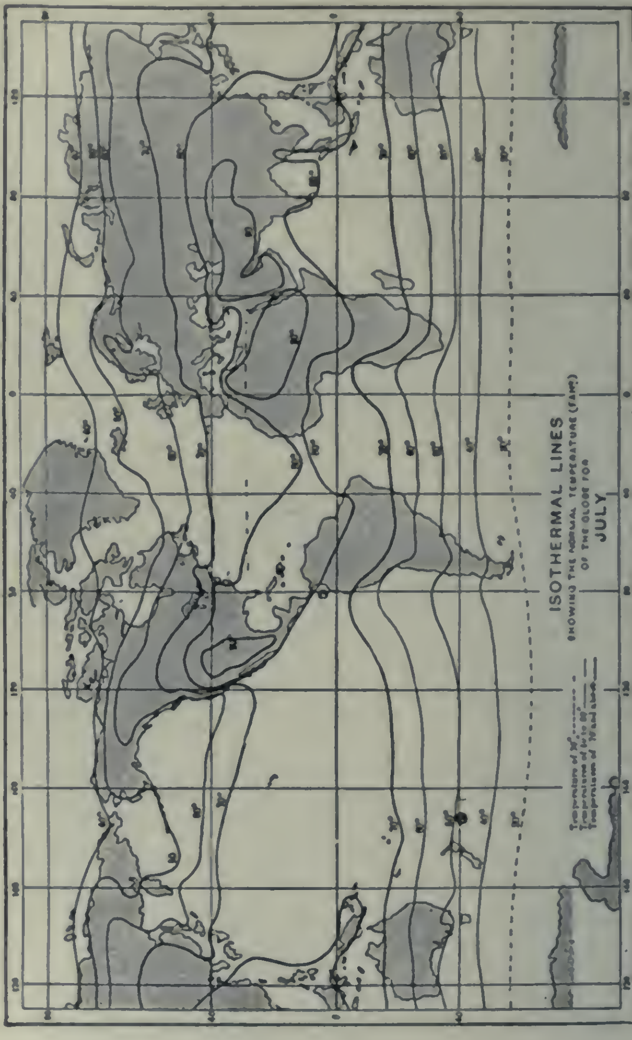


Fig. 10

Courtesy of The Macmillan Co.

a small portion of the land masses of the world. The hot belt is widest in South America, Africa, and India.

The isothermal maps of the world for January and July show that the hot belts migrate with the sun, and that both the highest and the lowest temperatures occur on the land. It will also be noticed that the lines are more regular over the water than over the land. Moreover, there is usually a sudden change in the direction of the isotherms as they pass from an ocean to a continent.

Practical Exercises

To compare by a drawing the effect of vertical and oblique rays in warming the surface of the earth.—Place a sheet of squared paper with one of its long edges next you; draw a heavy line across the middle of the sheet; trace heavily from the top of the sheet to this line two of the vertical lines three centimetres apart. Next, from the horizontal line draw upward two parallel lines three centimetres apart at an angle of 66° with the horizontal line. In a similar manner draw two parallel lines three centimetres apart, making an angle of 23° with the horizontal line. Measure the length of the part of the horizontal line intercepted by each pair of parallel lines. If the space between each pair of parallel lines represents a number of the sun's rays, compare the number represented in the three cases. If the horizontal line represents the earth's surface, compare the areas of the earth's surface covered by the rays in the three cases. Does a given area of the earth's surface receive more heat when the rays strike it vertically or when they strike obliquely? Give one reason (*a*) why a region is heated more intensely at noon than in the morning or in the afternoon; (*b*) why a region is warmer in summer than in winter; (*c*) why the earth is warmer in tropical than in temperate or frigid regions.

To study a thermograph record.—Figure 8 shows a temperature record of a thermograph for a part of October. Mt. stands for midnight, and the small figures along the top indicate the hours, while the larger figures indicate the days of the month. Find the range of temperature for each day. Find the hour of maximum temperature for each day. At what hour of the day is most heat received from the sun? Explain why the maximum temperature does not occur at this hour (Sec. 23). Find the hour of minimum temperature each day. From an almanac find the hour of sunrise at this time of the year. What is the relation between the hour of sunrise and the hour of minimum temperature? Explain this relation. At what part of the day is there the most rapid cooling? At what part is there the slowest cooling? Why?

To make and study seasonal graphs.—The following table contains the latitude, the longitude, and the mean monthly temperatures in Fahrenheit degrees of the places whose names are in the first column:

TABLE 3

PLACE	Lat.	Long.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Verkhoyansk	67°N	134°E	-58.5	-48.5	-26.5	7.3	35.6	54.1	60.6	50.2	36.5	5.0	-36.0	-52.6
London, England	51°N	0°	39.1	39.7	42.1	44.0	53.6	60.3	63.1	62.1	57.8	49.6	43.0	39.2
Manila	15°N	121°E	78.5	77.5	80.2	82.8	82.8	81.9	80.6	81.0	80.4	80.2	78.8	77.2
Buenos Aires	35°S	58°W	73.4	74.3	69.6	62.1	56.1	51.4	50.5	52.0	57.0	61.6	67.8	73.0
Vancouver	49°N	123°W	36	38	43	47	54	58	66	62	58	49	42	38
Winnipeg	50°N	97°W	-5	-1	14	37	52	63	66	63	53	40	20	3
Halifax	45°N	64°W	27	24	30	39	49	58	66	66	58	49	28	29

On a sheet of squared paper rule a rectangle 12 cm. by 15 cm. Place the paper with the short side of the rectangle toward you. Mark at the top of the centimetre lines the months of the year, beginning with January on the left and ending with January on the

right. On the left margin of the rectangle, mark temperatures beginning at the bottom with -60° and allow one centimetre for every ten degrees. Starting with Verkhoyansk, on the January line mark the point representing -59.8°. Mark the mean monthly temperature for Verkhoyansk on each of the other lines. Then with a coloured crayon draw a line through the thirteen points. This line is called a *temperature curve* or *graph*. In a similar manner draw graphs showing the annual range of temperature for each of the other places in the first column of the table. The graphs should be drawn with crayons of different colours. From the latitudes and the longitudes given in the second and third columns of the foregoing table, find on a map the location of each of the places. What is the range of temperature in each place? How do you account for the great range at Verkhoyansk? How do you account for the small range at Manila? Why is the curve at Buenos Aires so different from the others? How does the latitude affect the range? What cities are near large bodies of water? How does proximity to water affect the range of temperature? Explain the difference in the graphs for Vancouver and Winnipeg, and also for Vancouver and Halifax. Why do the graphs for Vancouver and London resemble each other so closely?

To draw the isotherms for January on a map of Canada.—Figure 17 is a map of Canada and adjoining parts of the United States. The figures indicate the mean temperatures of the localities for the month of January. In what provinces do temperatures below 0°F. prevail? Draw the line which separates the region in which the temperature is below 0°F. from the region in which it is above 0°F. To do this begin at the point marked 0°F., directly north of Edmonton. On which side of Prince Albert will the line pass? On which side of Winnipeg? Continue the line east and west to the

Atlantic and Pacific coasts. Mark the line in with red ink and mark 0°F. at each end of it. Such a line is called an *isotherm*. In a similar manner mark in red ink the isotherms for 40°F., 30°F., 20°F., 10°F., 0°F., –10°F., –20°F., –30°F. State approximately the tem-

Fig. 17.—Map of Canada, showing the mean monthly temperatures for January in different parts of the country

perature on the fiftieth parallel of latitude at 60° west longitude and at every tenth degree of longitude across the continent to the Pacific Ocean. What effect does proximity to the ocean have on the temperatures of places in Canada in January? Why? Which has the greater warming effect on the land, the Atlantic or the Pacific Ocean? Draw a line from Prince Rupert across the map to show the course of the most rapid lowering of temperature. Draw a similar line from Vancouver, and also one from Winnipeg. What relations have the directions of these lines to the directions of the isotherms? These lines are called *lines of temperature gradient*.

Which of the temperature gradients drawn shows the most rapid change of temperature? The isotherms in British Columbia are close together. What does this indicate? Where are they far apart? What is the significance of this? What change in direction takes place in all the lines as they approach the coast? Explain this. Write a paragraph on the distribution of temperature in Canada as revealed by your isothermal map. See that it contains answers to all the preceding questions.

To study isothermal maps of the world.—Study the map of the world (Fig. 14), showing mean annual temperatures. What is meant by mean annual isotherms? How are they obtained? What is the general direction of the isotherms? Explain why they have this general direction. Compare the isotherm of 40°F. in the northern with that in the southern hemisphere. Which runs more regularly? Why? Why does the isotherm of 40°F. bend so far north in the North Atlantic Ocean?

Figures 15 and 16 show the isotherms of the world for January and July. From a study of these maps answer the following questions: Where are the very cold regions in January? In July? Explain in each case why the regions are cold. In which month are the hot regions (over 80°F.) most extended? Why? In what general direction do most of the isotherms extend? Do the isotherms follow this direction more regularly in the northern or in the southern hemisphere? Why? In which hemisphere is the greater range of temperature between January and July? Compare the position of the different isotherms in January and July and explain the difference. On each map follow the fortieth parallel

of north latitude and set down the temperatures as indicated in the following table:

TABLE 4

Month	Pacific Coast of North America	Central United States	Atlantic Coast of North America	Mid-Atlantic Ocean	Coast of Spain	Central Asia	Japanese Coast	Mid-Pacific Ocean
July								
January								
Range								

Have the centres of the oceans or the centres of the continents the greater range of temperature? Explain the difference in the range of temperature between the east and west coasts of the United States. What change in temperature takes place in passing from the coast to the interior of a continent? Why?

CHAPTER IV

THE MOISTURE OF THE AIR

Preliminary Experimental Work

(*1*) *To show what is meant by evaporation.*—

Leave in the class-room an evaporating dish half filled with water. After twenty-four hours observe whether the volume of the water has changed. If so, explain the cause of the change in volume.

(*2*) *To show what is meant by condensation.*—

Put some cool water into a beaker the outside of which has been thoroughly dried. Add small pieces of ice gradually until a mist forms on the outside of the beaker. If a mist does not form when the ice is put in, add some salt to the water. What is the source of this moisture?

(*3*) *To illustrate the formation of a cloud.*—

(*a*) Heat some water in a flat metal vessel until it is almost boiling, place it on a window-sill, and open the window so as to allow the cold air from outside to sweep over the vessel. Notice the formation of a cloud above the surface.

(*b*) Hold a bell-jar for a few minutes over a jet of escaping steam from the spout of a kettle or the valve of a radiator until the air in the jar is thoroughly saturated with water vapour. Then place the bell-jar on the receiver of the air-pump. Notice the appearance of the contents of the jar after one or two strokes of the piston. Account for the phenomenon observed.

(c) Arrange apparatus as in Figure 18. *A* is a large bottle (the larger the better). *E* is a smaller bottle, containing some water *W*. Both have tightly fitting rubber corks, each with two elbow tubes. Two of the elbow tubes are connected by a short piece of rubber tubing with a pinch-cock *F* on it. The other elbow tube from *A* is connected with an air-pump. The second elbow tube from *E* has a piece of rubber tubing attached to it, and near the end of the rubber tubing is a pinch-cock *H*. The water should stand in *E* at least an hour before the experiment is continued. With both pinch-cocks closed, exhaust the air from *A* as completely as possible. Then suddenly open the pinch-cock *F*. This allows the air in *E* to expand suddenly to fill both bottles. A faint cloud appears in *E*. Close *F* and open *H* for a moment; then close it, and again exhaust the air from *A*. Allow a little smoke from a burning match to enter *E*; again insert the cork, and open *F*. A much denser cloud appears.

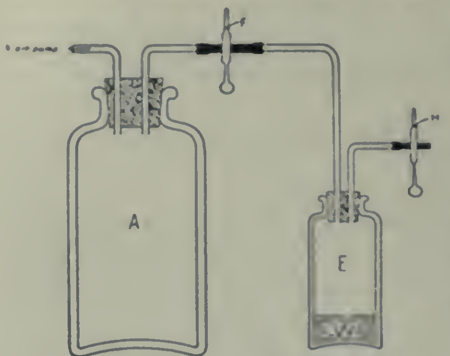


Fig. 18.—Apparatus for illustrating the formation of clouds
A and *E*, bottles
F and *H*, pinch-cocks
W, water in small bottle

(4) *To find the dew-point.*—

Add ice gradually to a polished metal cup half full of water, and stir the water constantly with a thermometer. On the first appearance of mist on the outer surface of the metal cup, read the thermometer. Repeat the experiment three or four times.

(5) *To show what is meant by a saturated solution.*—

Put as much pulverized blue vitriol as will lie on a five-cent piece into a test-tube containing two inches of water. Shake the test-tube until the blue vitriol is entirely dissolved. Note the length of time required to dissolve it. Add the same amount of vitriol to this solution, shaking the test-tube again until it is all dissolved. Again note the time required. Continue until no more vitriol will dissolve. We now have a saturated solution. Heat the solution and add vitriol as long as it will dissolve. Put the test-tube under a tap and let water run over the outside of the tube in order to cool the solution. What change takes place?

(6) *The relative humidity of the air as shown by a wet and dry hygrometer.*—

Read the temperature of the air as recorded on two thermometers placed side by side. Surround the bulb of one with a short piece of lamp-wick, the lower end of which is immersed in a vessel of water. When the mercury in this thermometer has ceased moving, read the two thermometers again. Explain the difference in temperature. Take a reading from these two thermometers under these conditions every day for a week. Is the difference between the two always the same? Explain.

THE WATER IN THE AIR

27. The water cycle.—If a vessel containing water is left exposed to the air, the contents gradually pass from the vessel and diffuse through the air. In the same manner the air is continually receiving water vapour from all bodies of water. Moist soil and plants, also, are continually giving water vapour to the air. This vapour is carried up by ascending air currents and may be transported thousands of miles by winds. But sooner

or later the air becomes chilled, the water vapour forms clouds, and the water particles in the clouds collect as rain or snow, which falls upon the earth. Part of this water is evaporated directly from the land. Part of it flows off the land into streams, by means of which it is carried back to the ocean, and from there it again passes into the air. Water passes continually through this cycle. In this way millions of tons of water are daily lifted into the air and transported.

28. The uses of water in the air.—To raise so much water requires a great amount of energy. This is supplied by the sun. As the water passes through the streams back to the sea, man recovers much of this energy and converts it into electrical power to run his factories or to light his houses and to perform many other services. The navigation of rivers and lakes depends on a constant supply of rainfall. Moreover, the vegetation of the world, and thus, directly or indirectly, most of man's industries, are determined largely by the amount and distribution of the rainfall.

29. Evaporation.—Water when in contact with air, acts much like vitriol when in contact with water. For example, if a lump of ice or a vessel of water is left in contact with the air, the ice or the water gradually diffuses into the air, just as the vitriol dissolves in the water. While it would be perfectly correct to say that the ice or the water dissolves in the air, it is more usual to say that it *evaporates*. Water dissolved in the air is in an invisible state and in this form is called *water vapour*. If the air remains in contact with water, it becomes *saturated* with water vapour. If the saturated air is heated, it will take up still more water vapour. But if warm air containing much water vapour is cooled, it will in time reach a temperature at which the air is saturated. This temperature is called the *dew-point*. If the air cools

below the dew-point, a part of the water vapour will usually condense as little, visible globules of water or as crystals of ice. The visible particles form a *cloud* or *fog*. If the air again becomes warmer, the particles redissolve, and the cloud or fog disappears. It was said above that when saturated air is cooled, a cloud usually appears. But it has recently been found that, if air is free from dust, it may be cooled many degrees below dew-point without causing any condensation of water vapour. This would appear to indicate that the dust particles are necessary to form nuclei about which the water may condense. It has, however, been discovered still more recently that, under certain conditions, even if dust is absent, the particles of the air itself form little, electrical nuclei, called *ions*, about which the water condenses. You have already seen how effective are smoke particles in forming nuclei for the condensation of water vapour. In country districts, where the air contains relatively few dust particles, fogs are less frequent than in great cities, where factories are pouring vast quantities of smoke into the air.

30. Humidity.—When air contains enough or almost enough water vapour to saturate it, it feels damp and makes objects in contact with it damp. Such air is said to be *humid*. When the air is humid, we feel extremes of heat or cold more keenly than when the air is dry. In summer, if the air is humid, one feels the heat much more than if the air is dry, for in the former case there is little evaporation from the surface of the body. In winter, on the other hand, if the air is humid, one feels the cold more. The humid air makes the clothing damp, and as moist air and clothing are better conductors than dry air and clothing, the body loses its heat more rapidly under these conditions.

It is necessary to distinguish *absolute humidity* from

relative humidity. The following table shows the quantity of water vapour contained by one cubic foot of saturated air at the temperatures indicated:

TABLE 5

Temperature Fahrenheit.	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
Grains of Water in a Cu. Ft. . . .	0.54	0.84	1.30	1.97	2.86	4.09	5.76	7.99	10.95	14.81	19.79

By absolute humidity is meant the amount of water vapour contained in one unit volume of air. Accordingly, the numbers in the bottom line of the table express the absolute humidity of saturated air at the different temperatures. To say that one cubic foot of air contains one gram of water vapour gives only partial information regarding its humidity. Such air in a hot desert would be exceedingly dry, while on a cold winter's day in Canada it would be very humid. The desert air is far from its dew-point, since its temperature is so high, while air of the same absolute humidity on a cold winter's day in Canada is very near its dew-point. The nearness of the dew-point expresses more exactly the state of humidity than does its absolute humidity. To express the nearness of the dew-point, the term relative humidity is used. It may be defined as the ratio the quantity of water vapour in the air at a given temperature bears to the quantity in it when saturated at that temperature. Suppose 1 cubic foot of air at 20°F. contains .65 grams of water vapour. According to the foregoing table 1 cubic foot of saturated air at that temperature contains 1.3 grams of water vapour. Therefore the relative humidity is .65/1.3, or 50 per cent. If the air just described were at 10°F., instead of 20°F., its absolute humidity remaining the same, its relative humidity would now be .65/.84, or 77 per cent. It is the relative humidity that determines whether air feels damp or dry.

31. Dew.—You have observed that on a warm day a mist will form on the outside of a pitcher of iced water. The little drops of mist rapidly become larger, and run together to form drops of water, and may become so large that they run down the outside of the pitcher. These drops must have come from the air. The iced water cools the glass vessel, and the glass cools the air immediately in contact with it. When this air falls below its dew-point, part of its water vapour condenses as a mist on the outside of the pitcher. As different currents of air come in contact with the cooled surface of the glass, more and more water vapour is condensed, and the drops become larger.

Dew is formed in precisely the same way. As soon as the sun sets, blades of grass, leaves, and other objects begin to cool owing to the radiation of their heat. Under favourable conditions these objects radiate heat rapidly, some, however, more rapidly than others. As they cool, the air in contact with them also cools. When the dew-point is reached, moisture begins to condense on their surfaces. Objects which are good radiators reach this point sooner than poor radiators, and, therefore, are usually covered most copiously with dew. As the condensation proceeds, the drops become larger and larger and run together to form dewdrops. Just as a blanket thrown over you when you are sleeping keeps you warm by preventing the heat of your body from being lost by radiation, so clouds in the sky prevent radiation from these objects on the ground, and, consequently, on cloudy evenings there is little or no dew. Moreover, if a wind is blowing, the air in contact with the radiating objects is being rapidly renewed, and as the air is warmer than the objects, they are prevented from cooling, and, accordingly, little or no dew forms. On summer evenings

when the sky is clear and the air is still, there is likely to be abundant dew.

Some interesting experiments have recently been performed which show that much of the moisture that goes to form dew comes out of the moist soil or is transpired by leaves. If in the evening an inverted vessel is placed on sod, in the morning it will be found that there is more dew on the inside than on the outside of the vessel; but if a sheet of glass is placed between the vessel and the grass, there will be little or no dew on the inside. This indicates that during the night the moisture in the soil is evaporated into the air and is then condensed on the surface of the vessel. Everybody who has walked through a meadow in the early morning has been struck with the very large amount of dew that has formed on the leaves. It is believed that much of this comes out of the leaves themselves, for they transpire much water vapour through the pores on their surface. In the evening when the leaves are cooled by radiation and the surrounding air is below its dew-point, this transpired water vapour at once condenses on their surfaces. It is very probable that at night water frequently exudes from the pores of the leaves. Much of the dew on leaves may come from this source.

32. Frost.—If the dew-point of the air is below 32°F., the temperature of radiating objects must fall below this point before any condensation takes place, and under these conditions the water vapour appears on their surface as tiny particles of ice. As the solid particles of ice do not run together, a coating of frost is spread over the surface. As more water vapour solidifies, layer after layer of these little solid particles is added to those already formed, until finally a snow-like covering is produced. This is called *hoar-frost*, or *white-frost*. Hoar-frost should be carefully distinguished from frozen dew,

which occurs if the temperature of the air falls below 32°F. after dew has formed.

If the temperature falls only two or three degrees below the freezing-point, the frost does not injure any but the most tender plants. But frosts that occur when the temperature is below 28°F., kill many plants by freezing the moisture contained in their cells. The consequent expansion bursts and destroys the walls of the cells. Such frosts are called *killing frosts*. As the plants afterwards turn black, these frosts are also known as *black frosts*.

As frosts do damage to crops to the extent of millions of dollars every year, it is of great importance to the farmer to understand the conditions that favour or prevent frosts. Many investigations have been carried on, in order to find methods by which frosts may be prevented. The most effective, it would seem, are good drainage and clean cultivation. The farmer should also know the probable dates of the last frost of spring and the first frost of autumn; for the date of planting almost all farm produce is regulated by the probable date of the last killing frost in the spring, and the time of harvesting many fruits and vegetables is largely determined by the probable date of the first killing frost of the autumn.

33. Clouds.—When the temperature of the air high above the surface of the earth falls below the dew-point, clouds are usually formed. If the temperature of the air is above the freezing-point, the clouds are composed of little particles of water, but if it is below the freezing-point, they are composed of ice crystals. These particles are heavier than air, but are prevented from falling by ascending air currents. Clouds are not all of the same density. If the air in a cloud continues to become cooler, the particles become larger by condensation of more water

on their surfaces. If the air becomes warmer, evaporation from the surface of the particles takes place, and so the cloud becomes less dense or may even disappear entirely. Evaporation sometimes takes place at one part of a cloud and condensation at another, and so the shape of the cloud is changed. The upper air currents also toss the clouds into the most fantastic shapes.

34. How the air is cooled to form clouds.—An ascending air current is subjected to a steadily decreasing pressure as it rises. Under a diminished pressure a gas expands. Accordingly, ascending air currents are continually expanding and becoming cooler. If this ascension continues, the air in time is bound to reach its dew-point, and then condensation begins, and a cloud appears. Almost all clouds are formed in ascending air currents. Other processes, such as the mixing of warm and cold air, or the blowing of warm, moist air over cold surfaces, play a very subordinate part in cloud formation.

As air descends, it is subjected to a steadily increasing pressure and decreases in volume. All gases, when compressed, become warmer. Consequently, descending air currents are continually rising in temperature. If air which contains a cloud begins to descend, the cloud becomes less dense or disappears as it reaches lower levels and as the air becomes warmer.

35. The forms of clouds.—From the earliest times man has been interested in clouds, and even now their forms, positions, and movements are the chief signs by which most people forecast the weather. On account of their variety and beauty of form, the delicacy of their colouring, and the rapidity with which they change both their form and their colour, clouds are among the most beautiful of all natural phenomena. Many attempts have been made to classify them. Three fundamental forms have entered into almost all classifications—*cirrus*,

stratus, and *cumulus.* The cirrus cloud (Fig. 19) is a small, detached, white cloud of irregular shape, made up of slender, delicate, irregularly curling fibres. It does not occur below an altitude of six or seven miles, and so is the highest of all clouds. The particles composing it

Fig. 19.—The cirrus cloud

are made of ice crystals, as the temperature at these high altitudes is always below the freezing-point, even in summer. The cumulus cloud (Fig. 20) is the grandest and most striking of our clouds. It is massive in appearance, being composed of dense, rounded masses. Its top is a dome with protuberances, while its base is flat. When seen opposite the sun, these clouds are white with dark centres. When viewed near the sun, they are dark with dazzling white edges. They are seen most commonly during hot afternoons in summer.

Stratus clouds, as their name implies, are low-lying horizontal sheets. Usually they are widely spread out

and obscure the sun, causing "gray weather." When a fog lifts from the earth, it forms a stratus cloud.

Fig. 20.—The cumulus cloud

Other forms of clouds are named by combining the above terms. For example, the names *cirro-stratus*, *cirro-cumulus*, *strato-cumulus*, etc., are used to describe clouds which have certain characteristics of the two fundamental forms designated by each name. The name *nimbus* is given to any cloud from which rain is falling. It forms a thick sheet and is very dark.

36. Fog.—A fog, or mist, has the same structure as a cloud, but while a cloud is suspended in the air, a fog rests on or moves along the surface of the earth. Fogs are usually caused in one of two ways. In the autumn, when the nights are lengthening, radiations from the lower stratum of air may cool a considerable depth of it below the dew-point, and so water vapour is condensed to form a fog which is observed in the morning. Again,

in the late winter, a warm, moisture-laden wind from the south may blow over the cold, snow-covered ground. The air is then cooled below its dew-point, and a fog is formed. The great fogs off Newfoundland are formed in this way. The warm, moist air from over the Gulf Stream blows across the icy waters brought down by the Labrador current. Fog disappears, either as the result of the air containing it being warmed by the sun, or because it is blown away by the wind.

37. Rain. — When a cloud is formed, minute drops of water condense about every dust particle. But the nuclei are so numerous that even if all the water vapour in the surrounding air were to condense about them, the drops would still be far smaller than rain-drops. However, as the air continues to rise, it leaves the heavier water drops of the cloud behind, and condensation at the higher level finds so few nuclei that a large accumulation of water condenses on each, and drops too heavy to be supported by the air currents are formed. These begin to fall, and as they do so, their electrical charges cause those that come in contact to blend. By this process, rain-drops are formed. The largest rain-drops are not more than one-sixth of an inch in diameter, and the average size of a drop is much smaller.

Sometimes a rain-cloud passes overhead, but only a few drops or none at all reach the ground. When this happens, the rain-drops fall rapidly, after leaving the cloud, through a stratum of dry air, in which rapid evaporation takes place from their surfaces, until they largely or entirely disappear.

Another phenomenon often accompanies a winter rain. As soon as the rain strikes an object, it turns into ice, and the surface of sidewalks, pavements, trees, telegraph-wires, etc., becomes coated with a smooth covering of ice. Frequently trees and wires become so heavily weighted

that they are broken down, and much damage is done. One explanation of this phenomenon depends upon the following facts. If pure water is not agitated, its temperature can be depressed far below the freezing-point without turning the water into ice. It is then said to be super-cooled. If the super-cooled water is agitated, the whole mass turns instantly into ice. The same phenomenon may occur with falling rain. If the temperature of the rain-cloud is above freezing-point and the layer of air through which the rain falls is below freezing-point, the rain-drops become super-cooled as they fall, and, when they strike a surface, the agitation causes them to solidify instantaneously. Rain-drops also freeze when, as occasionally happens, the temperature of the surface upon which they fall is below the freezing-point.

38. Snow.—If the temperature of air containing a cloud is below freezing-point, the particles forming the cloud are ice crystals, instead of water drops. As the crystals combine, they do not run together like liquid drops, but build up regular crystalline structures. When these become too heavy to be supported by the ascending air current, they fall as snow-flakes. Frequently they have very beautiful forms (Fig. 21), especially those that fall at the beginning or the end of a snow-storm.

Snow is of great importance to man. It forms a protective covering over the surface of the soil, and thus prevents frost from destroying the roots and the leaves of perennial plants. It is of value in supplying means of transportation, especially in the woods of the north, where the lumbermen are able to haul logs easily from the depths of the woods to the banks of streams only during the winter. Where snow falls to too great a depth, however, it may become a great hindrance to

Fig. 21.—Snow-flakes

Courtesy of The Macmillan Co.

transportation, blocking roads and railways for weeks at a time.

39. Hail.—Hail is not always, nor even usually, frozen rain-drops. During the winter rain-drops occasionally become frozen and reach the earth as clear pellets. But this is exceptional. Hail-storms usually occur on the hottest, most sultry days of summer and during the hottest part of the day. When hail falls, it invariably falls at the beginning of a thunder-storm during which there is violent thunder and lightning. Hailstones are composed of ice and snow in alternate concentric layers. They vary in size from very small pellets to the size of hens' eggs or even larger (Fig. 22). They are formed in

Courtesy of U.S. Dept. of Agriculture

Fig. 22.—Hailstones. Bottom of tray is 10½ inches long

violent cyclonic vortexes, in which they are sucked up to great heights and then drop, only again to be sucked up. At the lower levels they receive coverings of water, which freeze to ice in the cold, higher air, where they also receive coatings of snow or hoar-frost. Hail-storms

frequently do great damage to crops by battering their tender parts to pieces. Unfortunately, they are most frequent at the season when the crops are green and easily harmed. The grain crops of the Prairie Provinces of Canada sometimes suffer great damage in this way.

Practical Exercise

To study the formation of frost and dew.—(*a*) For two weeks observe in the evening whether the sky is clear or cloudy and whether there is any wind. In the morning observe whether there is any dew and whether it is copious or not. (*b*) Note the kinds of objects on which the dew is most copious and the kinds on which it is small in amount or absent. For this purpose, examine grass, the leaves of the lower branches of trees, pieces of wood, iron, etc. (*c*) Place an inverted metal pan over some grass in an open field. Examine the pan in the morning. Has dew been deposited on the outer surface? On the inner surface? Is there dew on the grass under the pan? Again, place the inverted pan in the field, but instead of placing it directly on the grass, insert a sheet of glass between it and the grass. Is there dew on the inside of the pan now? Does all the dew come from the air, or does some of it come from the soil and the grass? (*d*) During October and November repeat (*a*), only note if frost appears instead of dew. (*e*) If the school possesses a minimum thermometer, leave it in the grass during several nights, noting each night whether there is dew or frost and what is the minimum temperature during the night.

QUESTIONS

1. Why is dew more copious in hollows than on hills?

2. If the absolute humidity of the air is 2 grams per cubic foot and its temperature is 70°F., find its relative humidity (Sec. 30).

3. The dew-point is 30°F. at a place where the temperature is 70°F. Find the relative humidity at the place.

4. The rainfall in inches at a place for the twelve months of the year beginning with January is as follows: 1.9, 1.5, 1.2, 1.5, 1.9, 2.3, 2.2, 2.3, 1.6, 2.3, 1.8, 2.1. Construct for that place a rainfall graph for the year.

5. A moist, warm wind blows up on one side of a mountain and down the opposite side. Compare the rainfall and temperature conditions of the two sides of the mountain.

6. Why is dew more abundant on the grass than on the leaves of trees in the same vicinity?

7. What becomes of the white cloud that rises from a locomotive?

8. When there is danger of frost, the gardener sometimes builds a fire that produces much smoke. Explain how such a fire may prevent the destruction of his crop by frost.

9. Why is water vapour not found in the air at great altitudes?

10. Draw a diagram illustrating the water cycle (Sec. 27).

CHAPTER V

THE PRESSURE AND CIRCULATION OF THE ATMOSPHERE

Preliminary Experimental Work

(*1*) *To make a barometer.* —

(*a*) Place your thumb over the mouth of a test-tube full of water, invert the test-tube in a pan of water, and remove your thumb. Does the water run out of the test-tube? What is holding it up?

(*b*) Arrange apparatus as in Figure 23. *A* is a glass tube sealed at one end. It should be at least thirty-five inches long and have a bore as large as a lead-pencil. *B* is a piece of glass tubing of the same bore, eight inches in length. *C* is a rubber tube connecting *A* and *B*.

Holding these in the position shown in Figure 23, pour mercury into the opening of *B* until *A* and *C* are filled. Keeping *B* in a vertical position, raise *A* until it also is vertical, as shown in

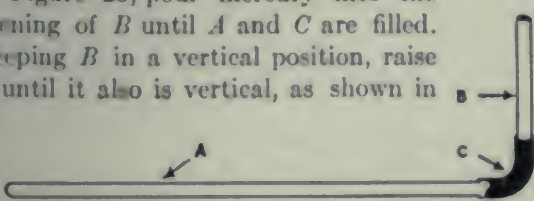


Fig 23

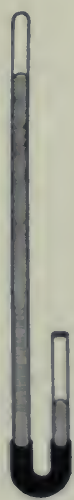


Fig 24

Figure 24. Note the height of the mercury in the two tubes. Measure the distance between the levels of the mercury in them. Account for the difference in level.

(2) *To show that the height of the column of mercury varies as the pressure of the air.*—

Make a barometer as in the preceding experiment, but having the open arm almost as long as the closed arm. By means of the air-pump or by suction of the mouth, partially exhaust the air from the open arm. Note any change in the height of the column of mercury in the closed arm. Account for the change.

(3) *To compare the density of liquids.*—

Weigh an empty specific gravity bottle. Fill it with mercury and weigh again. Repeat the experiment with glycerine and again with water. Calculate the weight of this volume of each of the liquids. How many times as heavy as water is (*a*) mercury, (*b*) glycerine?

(4) *To show the effect of altitude on pressure.*—

Examine the graduations on an aneroid barometer, in order to learn what difference in pressure is indicated by each graduation. Read the pressure near the floor of the basement of the school as registered by the aneroid barometer; then read the pressure at the highest point in the school it is possible to reach. Assuming that a difference in pressure of one-tenth of an inch indicates a difference in altitude of ninety feet, calculate the difference in height between the two places whose pressures have been measured. By means of the aneroid barometer find the height of the highest hill in your vicinity.

(5) *To study convection currents in air.*—

(*a*) On a calm day close all the windows of a warm room and also all the doors except one that opens directly outside. Leave this door very slightly open, so that there is a narrow chink. Place a burning candle near the top of the chink and gradually lower it to the bottom. The deflections of the flame indicate the directions of the

air currents. Note the direction of the air currents at different heights along the chink. Hold a thermometer near the top and then near the bottom of the chink in order to find the temperature of the currents. Give reasons for the differences of (*a*) temperature, (*b*) direction of the air currents.

(*b*) Perform experiment described in last paragraph of section 362, *Elements of Physics* (Merchant & Chant).

(6) *To show the effect of centrifugal force on rotating bodies.*—Fill a circular wash-basin with water. Then pull the plug from the outlet, and quickly give the water a swirling motion with your hand. What is the effect of the swirling motion on the level of the water (*a*) near the centre of the basin, (*b*) near the margin?

THE PRESSURE AND CIRCULATION OF THE ATMOSPHERE

40. Why the air exerts pressure.—Every particle of air is drawn toward the centre of the earth by the force of gravity. This gives to the air its weight. Just as a stone presses against the surface on which it rests, so the atmosphere presses against all surfaces on the earth with which it is in contact. The amount of pressure exerted by the air at any point depends partly on the height and partly on the density of the air above that point. If the height of the air above any point is great and the air is dense, the pressure is great. As warm air is not so dense as cold air, the pressure in a cold region is usually greater than in a warm region, other conditions remaining the same. If the upper air becomes heaped above a point, the pressure at that point is increased. Probably the moisture of the air has some slight effect upon the pressure. A volume of water vapour weighs little more than half as much as the same volume of either oxygen or nitrogen—

the two chief components of air. In a mass of humid air, water vapour replaces some of the oxygen and nitrogen; and so the weight of the mass is less than if it were composed entirely of dry air. Thus temperature and humidity both play a part in producing the varying pressures found at different portions of the earth's surface. The part played by temperature is much the greater of the two, for, as we shall see (Sec. 45), the changes of temperature disturb the balance of pressure in adjacent regions, and so are the primary causes of the movements of the air that we call *winds*.

Fig. 25 — A mercurial barometer

41. The measurement of the pressure of the air.—While changes of temperature affect man greatly, he is entirely unconscious of the many changes of pressure that are continually occurring. Yet to the man who wishes to forecast the weather or to understand the climate of a country, the changes of pressure are fully as important as those of temperature. Hence it is of great value to him to have an instrument that will measure the pressure of the air with a high degree of accuracy.

Such an instrument is called a *barometer*. The kind generally used is the *mercurial barometer*. In this instrument (Fig. 25) the pressure of the atmosphere is balanced by the pressure of a column of mercury, and, as the atmospheric pressure increases, the column of mercury necessary to balance it increases in height. Thus the height of the column of mercury measures the pressure of the air. At the level of the sea the average height of the mercury column is about thirty inches. Hence it is said that the pressure of the air at sea-level is thirty inches. Mercury is used in the barometer

chiefly because its density is so great that a short column of it is heavy enough to balance the column of air. A water barometer would have to be about twelve yards long, in order to contain a column of water high enough to balance the air pressure. Mercury, however, has one decided disadvantage. Owing to the great density of mercury a small change in the pressure of the air causes so slight a movement of the mercury that it is difficult to measure it accurately. In *The Times* Office, London, England, there is a glycerine barometer twenty-eight feet high, the readings of which are given in that newspaper every day. An increase in air pressure that causes the mercury in a barometer to rise an inch, causes glycerine to rise almost a foot; hence the slightest changes of pressure are readily detected by *The Times'* barometer. Another disadvantage of the mercury barometer is that it is not easily carried about, though it is sometimes constructed in a portable form. A barometer without any liquid in it is generally used by explorers when making observations. Such a barometer is called an *aneroid barometer* (Greek *a*, not, *neros*, wet). In this instrument the pressure is indicated by a hand that moves on a pivot around a graduated dial. Aneroid barometers have to be frequently adjusted by comparing them with mercury barometers. Many aneroid barometers have such words as "stormy," "rain," "fair," and "very dry," on them, but such words have little significance. As will be learned later (Sec. 54), it is not the pressure itself that indicates the kind of weather, but rather the way in which the pressure changes.

42. Pressure and altitude.—The pressure of the air is not the same at all levels. When we climb a mountain, for instance, the amount of air above us becomes less as we ascend, and, consequently, the pressure diminishes also. On the other hand, as we descend, the pressure

of the air increases. For heights not far above the sea-level, the pressure, as measured by the mercurial barometer, decreases one-tenth of an inch for every increase of ninety feet in elevation. A knowledge of this fact enables men to use the barometer for measuring the altitude of mountains. All aeroplanes, airships, and balloons carry aneroid barometers, by which the pilots can tell how high they are above the earth. On certain maps of different parts of Canada prepared by the Department of Militia and Defence, it is stated that the elevations shown were obtained partly by means of an aneroid barometer.

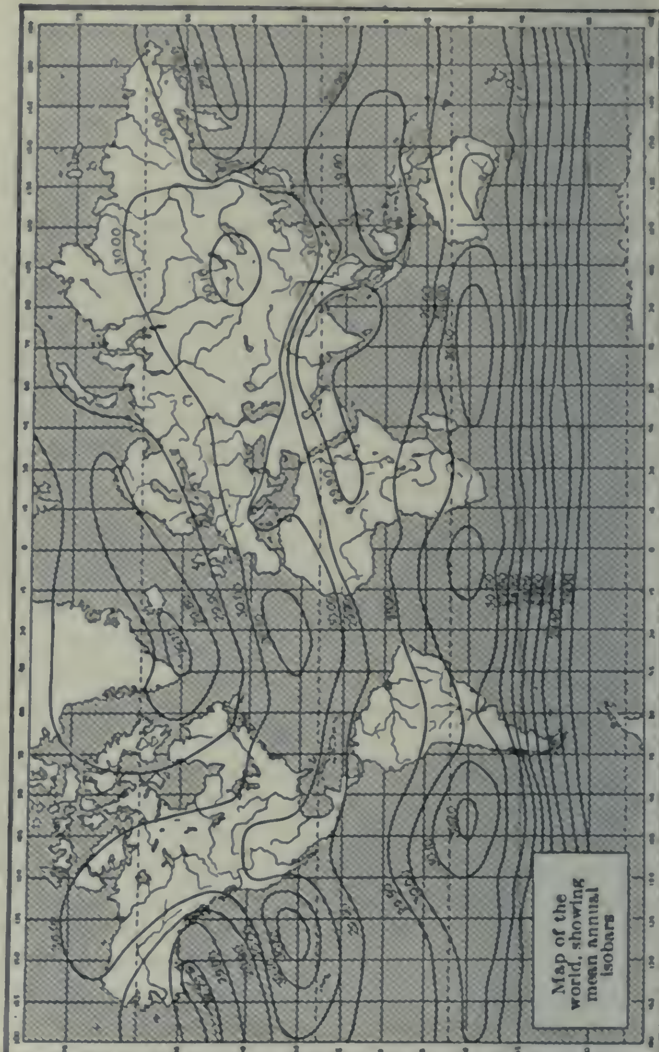
As an indication of how pressure decreases with increase of elevation, a table of localities with approximate heights and pressures is given.

Locality	*Altitude*	*Pressure*
Halifax, N.S.	0	30 in.
Ingersoll, Ont.	900 ft.	29 in.
Dundalk, Ont., (the highest point in southern Ontario)	1704 ft.	28 in.
Yellowhead Pass, B.C.	3800 ft.	26 in.
Colorado Springs, U.S.A.	5900 ft.	24 in.
Bogota, Colombia	8200 ft.	22 in.
Leadville, Colorado	10600 ft.	20 in.
Vincent, Bolivia	16000 ft.	17 in.

43. Periodic variations in pressure.—But pressure is not dependent on altitude alone. The pressure at the same place varies from day to day and from hour to hour in a very irregular manner, depending on changes of temperature, cloudiness, humidity, and wind. But besides these irregular variations, there is a regular slow, daily change from a maximum to a minimum pressure. When other conditions which affect the pressure remain steady, the pressure reaches a maximum at 10 a.m. and a minimum at 4 p.m. In the equatorial regions of the oceans, where disturbing influences are few, these changes are so regular that one could almost use a barometer for telling time.

In addition to the irregular variations and the regular daily change, there is also a regular seasonal change. During the summer the land becomes hot, while the water remains relatively cool; during the winter the opposite conditions obtain, the land becoming much cooler than the sea. Accordingly, over the land the pressure is highest during the winter and lowest during the summer, while over the sea it is highest during the summer and lowest during the winter.

44. Isobaric maps.—As daily records of pressure have been kept for many years at thousands of stations scattered over the world, and as many more records of pressure taken by ships in almost all parts of the oceans are available, it is possible to find the average daily, monthly, and yearly pressure for almost all portions of the earth. In fact, such records, based on more than fourteen million observations, were compiled by Dr. Buchan in 1888, and entered on maps of the world. A map that has the average pressure for each place entered on it, with lines drawn through places of equal pressure, is called an *isobaric map*, and the lines are called *isobaric lines* or *isobars.* Figure 26 is a map of the world showing the mean annual isobars. This map shows the following general distribution of pressure over the earth: (*a*) The lines run in a general east-west direction and are more regular in the southern than in the northern hemisphere. (*b*) A belt of low pressure encircles the earth between the tropics. (*c*) Belts of high pressure encircle the earth at about 30° north and 30° south latitude. These belts have peaks of still higher pressure over the oceans. In Asia the northern high-pressure belt is bent northward. (*d*) South of the southern belt of high pressure is a belt of low pressure. In this belt the pressure steadily decreases southward as far as the Antarctic Circle; beyond this there appears to be an



Map of the world, showing mean annual isobars

Fig. 20

increase of pressure. The low-pressure cap toward the north pole is not so marked, probably on account of the large masses of land in the northern hemisphere; but over the ocean there is a steady decrease in pressure toward the north pole.

THE GENERAL CIRCULATION OF THE ATMOSPHERE

45. Temperature and pressure.—Differences of atmospheric pressure at the same level of the air are primarily caused by differences of temperature. As we already know, a rise in temperature causes air to expand, and a fall in temperature causes air to contract. As we have seen (Sec. 22), the air receives its heat chiefly from the heat of the sun which has been absorbed by the earth's surface. Consequently, the lower layers of the air are the first to become heated, and, as they expand, the higher air is pushed upward by the expansion of the air beneath, and so flows outward in all directions from above the heated area (Fig. 27). Since the actual mass of air

Fig. 27 —Diagrams to illustrate the cause of circulation of air

above this area is thus decreased, the pressure becomes less. Such an area, where the heated lower air, by its upward expansion, has caused an outflow of air at higher levels, is called an *area of low pressure.*

Very different are the conditions in the cooler areas surrounding the area of low pressure. In consequence of the outflow of air at high levels from above the heated area, there is an actual increase of the mass of air

above the surrounding regions. Consequently, the weight of air over these areas is greater, and so the atmospheric pressure is increased. Such regions we call *areas of high pressure.*

Because of the increased weight above, the air at the surface of the earth in a high-pressure area is compressed to a greater extent than the air at the corresponding level of an adjoining low-pressure area. We know that the compressed steam in a boiler is driven, by the pressure to which it is subjected, through the radiators of a building, overcoming in its progress the weaker pressure exerted by the air in the pipes and radiators, and driving the air before it. In somewhat the same way the compressed air at low levels in a high-pressure area forces its way inward toward the low-pressure area. This inflow of cooler, denser air at low levels forces the warmer, rarer air upwards, takes its place, and then, itself becoming heated, is forced upward in its turn.

In this way a circulation of air between a low-pressure area and surrounding high-pressure areas is begun. As long as the supply of heat is maintained, the circulation continues. Such air movements, caused by differences of temperature in adjacent areas, are known as *convection currents.*

Let us now summarize briefly the chief points to be remembered regarding convection currents. Wherever adjacent regions have different temperatures, definite pressure changes and air movements result. In a region of comparatively high temperature, a low pressure is produced, accompanied by inflowing winds close to the earth's surface and by an upward and outward movement of the air at higher levels. In a region of comparatively low temperature, a high pressure is developed, accompanied by outflowing winds close to the earth's surface and by inflowing air movements at higher levels.

Surface winds, therefore, invariably move from areas of high pressure toward areas of low pressure.

46. The effect of the earth's rotation upon atmospheric pressure.—If we apply these principles to the earth as a whole, we should expect to find a slow but steady increase of pressure from the equator to the poles, corresponding with the decrease of temperature. But the map of the world showing the annual isobars (Fig. 26) indicates clearly that such is not the case. The distribution of temperature over the earth's surface accounts for the low-pressure area in the region of the equator, but fails to account for the two high-pressure belts at 30° north and 30° south latitude or for the low-pressure belts found north and south of these areas. For an explanation of these phenomena we must seek another cause.

The rotation of the earth affects the direction of winds blowing over its surface. In the northern hemisphere it deflects winds, no matter in what direction they are blowing, to the right of their course; in the southern hemisphere, to the left of their course. This is called *Ferrel's Law*, as William Ferrel, an American school teacher, first gave an adequate explanation of the deflection of winds by the rotation of the earth. So far as north and south winds are concerned, this law means that winds blowing toward the equator in either hemisphere are deflected toward the west, while winds blowing toward the poles in either hemisphere are deflected toward the east. Winds blowing toward the east in either hemisphere are deflected toward the equator, while winds blowing toward the west are deflected away from the equator.

Let us now take this new factor into account. The heated area of the equatorial belt produces an area of low pressure, from which outflowing currents at high levels move poleward, just as we should expect from our

knowledge of convection currents. But these upper air currents are deflected more and more toward the east (see Ferrel's Law). Between 30° and 40° north and south latitude, the deflection becomes so great that the poleward movement is much retarded, and the upper air currents move around the world in a more easterly direction, nearly parallel with the equator. Consequently, the upper air moving from the equator tends to accumulate in these latitudes, producing two belts of very high pressure at the surface of the earth. Furthermore, these great swirls of air circling around the earth, one with the north pole as the centre about which it circles, the other with the south pole, tend to reduce the amount of air near their centres, exactly as a swirl of water in a basin reduces the amount of water in its centre. This produces the low-pressure area found on the poleward side of each of the great high-pressure belts, and helps to build up the two high-pressure belts as well.

Fig. 28.—Diagram representing the general atmospheric circulation. The thin arrows represent the surface winds, the thick arrows the upper air currents.

47. The general circulation of the atmosphere. — In order to understand the general circulation of the air, the following two rules must be applied: (*a*) All winds blow from high-pressure areas toward low-pressure areas. (*b*) These winds never blow directly toward low-pressure areas, but

are deflected toward the right in the northern hemisphere and toward the left in the southern hemisphere.

Figure 28 illustrates the general circulation. From a study of it the following winds can be recognized:

(*a*) The *trade-winds*, blowing from the high-pressure belts near the tropics to the low-pressure belt at the equator, but deflected to the west because of the rotation of the earth.

(*b*) The *westerlies*, blowing from the high-pressure belts at the tropics toward the low-pressure belts near the poles, but deflected to the east (see Ferrel's Law).

(*c*) The *upper air currents*, flowing from the equator toward the poles, but quickly deflected to the east like the westerlies.

The trade-winds are continually bringing air from tropical regions toward the equator. This air does not accumulate at the equator, but is carried upward by expansion. Therefore in that region there are continuous ascending air currents. Since ascending air currents are not felt as winds at the surface of the earth, this region forms a belt of calms, called the *doldrums*, or *equatorial calms*.

At the high-pressure belts near the tropics, winds are blowing out toward both the poles and the equator. Consequently, in these belts there must be a descending current to supply air for these surface winds. As descending air currents are not felt as winds, these belts, also, are regions of calms. They are usually spoken of as the *horse latitudes*, or *tropical calms*. As there are both a surface wind and an upper air current blowing from the horse latitudes toward the poles, there must be an intermediate counter current blowing from the poles, as otherwise air would accumulate at these latter points.

The belts of winds and calms are not stationary, but migrate north and south with the seasonal progress of the sun (Fig. 29).

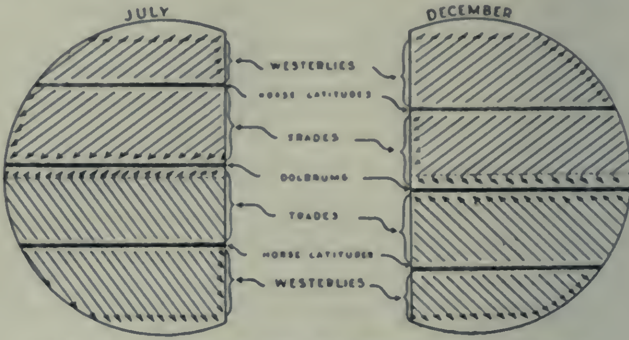


Fig. 29.—Diagrams to show the shifting of the wind belts between July and December

The foregoing must be considered as only a partial description of the general circulation, which is in reality much more complex than is here indicated. Recently it has been discovered that there are not merely two air currents in the equatorial regions, namely, the trade-winds and the upper air currents already described, but no fewer than five currents at different levels.

48. Effects of the distribution of land and water on pressure and winds.—The circulation of the air is affected by many other factors. One of the chief of these is the distribution of land and water. This factor produces both daily and seasonal changes. During the day the land warms more quickly than adjacent water. Consequently, the land becomes an area of comparatively low pressure, and a wind blows from the water to the land. This wind is called a *sea breeze.* At night the land cools to a lower temperature than the adjacent water, and a wind, called the *land breeze*, blows from the land toward the water. These winds are familiar to all who live close

to the shores of the Great Lakes, but are most marked in small oceanic islands and along the sea-coast. The fisherman takes advantage of the land breeze to carry his sailing-boat to the fishing-grounds in the early morning, and of the sea breeze for the return trip in the afternoon. During the summer the land is warmer than the sea, and the winds tend to blow from the sea to the land. During the winter the sea is warmer than the land, and, consequently, the winds tend to blow from the land to the sea. The effect of the large land mass of Asia on winds and pressure is very great. During the summer, when the sun shines almost vertically on the vast plateau in its interior, this region becomes an area of very low pressure, lower even than that at the equator to the south. As a result, the south-east trade-wind crosses the equator (Fig. 30), turns toward the east, and blows over India and south-eastern Asia as a south-west wind. This wind blows steadily throughout the summer, while during the winter the north-east trade-wind blows from the opposite direction. Because the winds of this region blow from one direction during the summer and from the opposite direction during the winter, they are called *monsoons*, an Asiatic word which means seasons. Wherever the trade-winds blow across the equator they are deflected (see Ferrel's Law), and monsoons are usually produced. For example, the interior of Australia is heated to a very high degree during the summer (December to February) and becomes a region of low pressure (Fig. 26). Under these conditions the north-east trade-wind crosses the equator and is deflected to the south-east over northern Australia. As in this region during the winter (June to August) the trade-wind blows from the south-east, monsoons are well developed. Monsoons also blow on the coast of the Gulf of Guinea in West Africa and in the region of

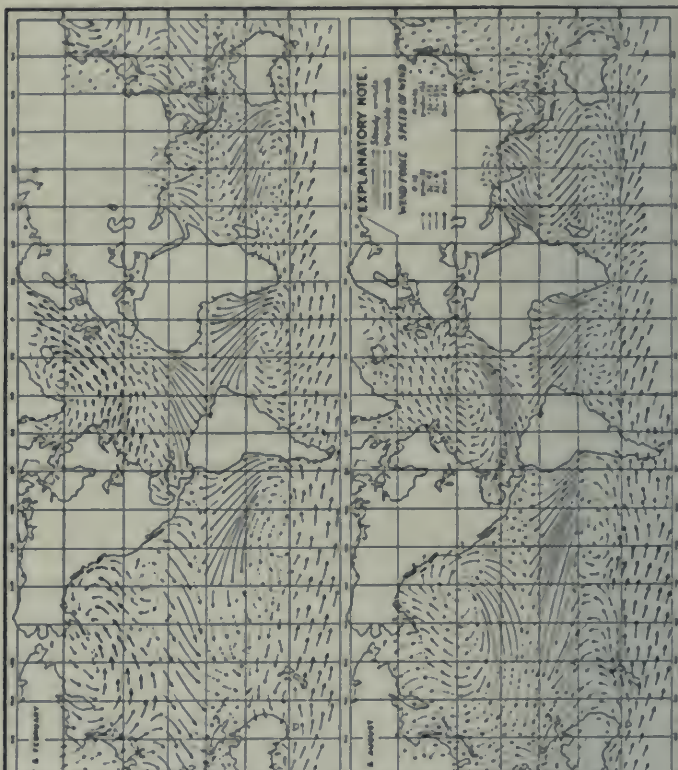


Fig. 30.—Chart of prevailing winds over the oceans

the Gulf of Mexico; but in these regions they are not so well defined. All these winds are shown in Figure 29.

The Winds and Calms

49. The trade-winds.—The trade-winds are undoubtedly the most important of all the winds. They blow between 30° north latitude and 30° south latitude, thus covering almost one-half of the surface of the earth. In Canada the direction of the winds at any one locality often changes from day to day. In the trade-wind belt, on the contrary, it is not uncommon to have the same steady wind for weeks together, especially on the sea. On the land the trade-winds do not blow so regularly as on the sea, but even there they are much more constant than the winds of Canada. The climate of the trade-wind belt on the sea and on lowlands is the simplest and most regular in the world. There it is not necessary to give forecasts of the weather, for one can be almost certain that to-morrow will be much like to-day and yesterday. A beautiful, clear sky with little rain, an even temperature varying little from day to day or from month to month, and a cool, refreshing breeze of from ten to thirty miles an hour, blowing from the north-east or from the south-east, make this belt unique. These winds have a marked influence on the world, politically, commercially, and physically. Their steady power carried many daring navigators to new lands. It was in the path of the north-east trade-wind that Columbus was carried to America. These winds have had great influence on trade, as sailors plying to India, Australia, and South America have always chosen the routes that would bring to their aid the steady winds of the trade-wind belt.

Still more important is the effect of the trade-winds on climate. As they blow toward the equator, they

grow steadily warmer, and hence become drying winds. Consequently, where they blow over the ocean or over lowlands, there is little or no rain. Indeed, most of the great deserts of the world are due to these drying winds. For example, almost all the great deserts of Australia, southern Asia, Africa, and western, south, and middle America are in the trade-wind belt. However, where the trade-winds strike sloping land surfaces, which cause them to be deflected upward, the air is cooled, and the resulting rainfall is copious. Therefore the windward sides of mountains that stand in the course of the trade-winds have heavy rainfall, while the leeward sides are deserts. This is the condition of the Andes west of Brazil, of the mountains of Mexico and Central America, and of such mountainous islands as Hawaii, Madagascar, and Teneriffe.

50. The doldrums.—Between the two trade-wind belts lie the *doldrums*—one of the most uncomfortable regions in the world. Sailors breathe a sigh of relief when their ships escape from its tenacious grip, but the less fortunate landsmen have to endure its enervating monotony. Here the trade-winds meet, and, consequently, there is a steadily ascending current of air. As has been explained in Section 34, an upward current produces cloudiness and rain. Here are light, baffling breezes and frequent calms. Each afternoon or evening the leaden, overcast sky pours down torrents of rain, accompanied by the most violent thunder and lightning. In fact, so heavy is the rainfall that the surface water of the sea is much less salty here than in the trade-wind belts to the north and the south. As the doldrums move north and south with the sun (Fig. 29), certain regions within their range have annually two rainy seasons, each followed by a dry season (Sec. 65).

51. The westerlies.—The westerlies blow beyond the tropics in a north-easterly direction in the northern hemisphere, and in a south-easterly direction in the southern hemisphere. In the region of the westerlies conditions are very different from those in the trade-wind belt. The winds are not nearly so regular, sometimes even blowing from all points of the compass in a single day. Storms, in the form of great cyclonic whirls, move over this region from west to east, producing frequent variations of weather in a short space of time (Chapter VI). Rainy and clear weather occur much less regularly than within the trade-wind belt. In the southern hemisphere, where there is less land, the westerlies are much steadier and of greater velocity than in the northern hemisphere. There they are called the "brave west winds," and the region in which they blow is known as the Roaring Forties. In the region of the westerlies the west sides of the continents have the greatest precipitation, while there is a steady decrease of rainfall toward the centre of the continents or beyond.

52. The tropical calms.—Lying between the regions of the trade-winds and the westerlies are the tropical calms or horse latitudes. As the winds blow out both north and south from each of these belts, there must be a settling down of the air from above, to replace that which goes to form the trades and the westerlies. Descending currents become warmer and more drying and so evaporate any clouds that may be in the sky (Sec. 34). Accordingly, this is a rainless region of clear skies, and of light winds, variable in direction and of low velocity. Calms are very frequent. Sailors do not dread the tropical calms so much as the doldrums, for, although the temperature is high and the winds uncertain, the air is not so humid and depressing. These calms, like

the doldrums, migrate north and south with the sun (Fig. 29).

53. The monsoons.—The monsoons blow throughout the summer in one direction and throughout the winter in the opposite or nearly opposite direction. In southern Asia they blow during the summer from the south-west, across India to beyond the Himalayas. As they blow over the Indian Ocean from the south, they become warm and moist. When they are forced upward by the slopes of the mountains, very heavy falls of rain and snow result. India is dependent on this precipitation for the growth of its crops. If the summer monsoon fails, as it occasionally does, the crops are likely to be ruined. Formerly the failure of the monsoon would cause the death of millions of the inhabitants, but now, as much water is stored in reservoirs and distributed through great irrigation works, the results are less disastrous. During the winter the north-east monsoon blows down from the great plateau of Central Asia, bringing cool, dry weather. Before steam-power made sailors independent of the wind, the monsoons had a marked influence on the routes of vessels. For example, ships from Europe formerly could make only one round trip a year to the Indies, as they were compelled to go with the south-west monsoon and return with the north-east monsoon.

Practical Exercise

To study the distribution of pressure from a map of the world showing annual isobars.—Figure 26 is a map of the world with the mean annual isobars marked on it. What is the general direction of the isobars? Do they run north and south for any great distance? Do the lines run more regularly in the northern or in the southern hemisphere? Where are the two most extended high-pressure belts? These are the *Northern Tropical High*

and the *Southern Tropical High.* Which is the more regular, the Northern or the Southern Tropical High? Give the reason. Are the Tropical Highs wider over the oceans or over the continents? What exception is there? Where is the Northern Tropical High widest? Where are the "peaks" in the Tropical Highs? What relation have the "peaks" to the west coasts of the continents? What pressures are found on each side of the equator? This region is the Equatorial Low. Where is the Equatorial Low widest? In what two regions has it the lowest pressure? Describe the pressures in the region south of the Southern Tropical Low. No records are marked beyond 60° south latitude. Why? What pressures would you expect to find in this region? Is there a similar condition in the Arctic regions? Where is the highest pressure found? Does temperature alone determine pressure? State your reasons if you think that it is not the chief factor. Have land and water any effect in determining pressure? If so, describe and account for their influence.

QUESTIONS

1. The reading of an aneroid barometer at the surface of the earth is 29.95 inches. At the bottom of a mine it is 30.89 inches. What is the approximate depth of the mine? (Sec. 42)

2. An aneroid barometer registers 29.56 inches at the base of a hill 2,500 feet high. What is its reading at the top of the hill? (Sec. 42)

3. Borneo, Ceylon, the Philippines, and the Falklands are all mountainous islands. Which side of the mountains receives the most rain? Give the reason in each case.

4. Account for the fact that northern Chile is a desert while southern Chile has an abundant rainfall.

5. The prevailing winds have largely determined the location of the chief settlements in Australia. Show this statement to be true.

6. Panama has one rainy season, Bogota has two. When do these rainy seasons occur? Give reasons for your answer.

7. Why is one side of a mountain range usually well watered, while the other is dry?

8. Sailing vessels make the voyage from England to Australia around the Cape of Good Hope and return across the Pacific and around Cape Horn. Why do ships take these routes?

9. The sailing route from Australia to Vancouver is north-east to the equator, then north-west from the equator to the horse latitudes, then north-east to Vancouver. What advantages are derived from taking this route?

CHAPTER VI

WEATHER

Cyclones and Anticyclones

54. Nature of cyclones and anticyclones.—You have often noticed little whirls or vortexes of water moving along in the current of a stream. On a summer day when the roads are dusty, a vortex of dust-laden air is frequently seen above the road, moving along before the wind. If we could look down from above upon the atmosphere of the earth, and if we could see the motions of the air, we should observe a procession of huge vortexes, each from 1,000 to 2,000 miles in diameter, drifting around the world from west to east in the westerly winds. Occasionally we should see a vortex weaken and disappear; again we should see others gradually form and take their places in the procession eastward. This procession of air vortexes passing over a place determines its weather. Since these vortexes move with a certain regularity and can be located by means of the barometer, we can forecast the weather in the temperate zone with fair accuracy.

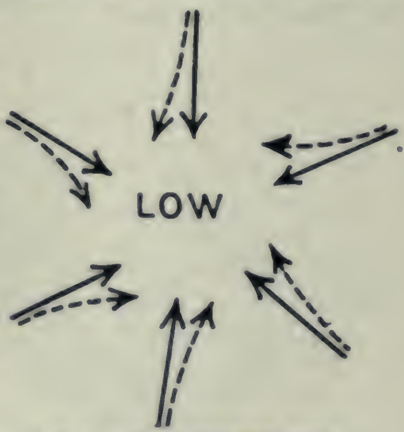


Fig. 31.—Spiral deflection about a low-pressure area

If the pressure of the air in one region becomes slightly lower than in the surrounding regions, air currents at once begin to move from all sides toward the region of low pressure, even though the difference in pressure is so small that a barometer would scarcely detect it (Fig. 31). On account of the rotation of the earth these air currents are all deflected to the right in the northern, and to the left in the southern hemisphere (Sec. 46). Because of this deflection the winds move spirally toward the depression. There are two important effects of the centrifugal force caused by this spiral movement. (*a*) As the winds advance toward the centre of the whirl, their velocities increase. (*b*) The pressure toward the centre of the vortex is decreased, while toward the margin it is increased. Accordingly, the barometer registers a region of low pressure at the centre of such a whirl. Thus the pressure conditions which we noted as essential for the setting of air currents in motion are intensified by the winds so caused. As the wind blows spirally inward, the crowding together of the air is relieved by an ascending current, which, though occurring in all parts of such a whirl, becomes more pronounced toward the centre. As was learned in Section 34, ascending currents become cool, producing clouds and precipitation. Accordingly, toward the central part of such

Fig. 32.—The elements in a cyclone

a vortex, cloudy weather with rain is usually experienced (Fig. 32).

When a region has a slightly higher pressure than surrounding regions, the air blows spirally outward from that region. As in such a vortex the wind is moving outward from the centre, the air must be supplied from above by a descending air current. Such a high-pressure area with descending air currents will have clear weather

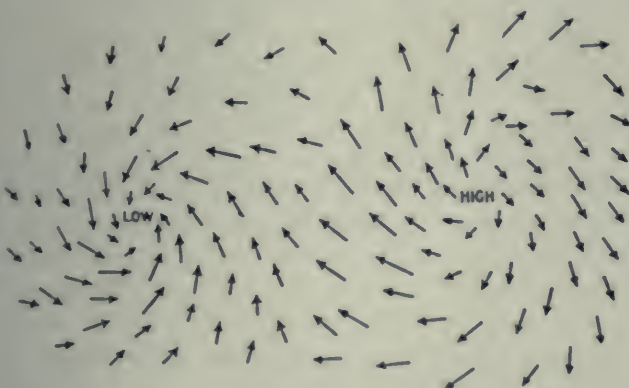
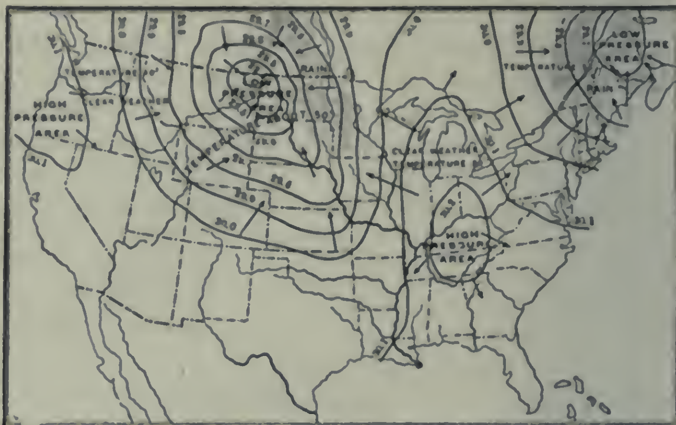


Fig. 33.—The winds in a high and a low

(Sec. 34). Figure 33 shows the winds in a low-pressure and in a high-pressure area, side by side. The great spiral inflow of air toward a central low-pressure region is called a *cyclone*, and the great spiral outflow from the region of high pressure is called an *anticyclone.*

Figure 34 shows a part of North America, with a cyclone over Eastern Canada and an anticyclone over the Central Mississippi States. The isobars are marked in continuous lines. The pressure at the centre of the low is 29.5 in. and at the centre of the high 30.5 in. In front of the low the winds blow from the south and south-east and bring warm weather. As the centre of the cyclone is



Courtesy of The Macmillan Co.

Fig. 34

Courtesy of The Macmillan Co.

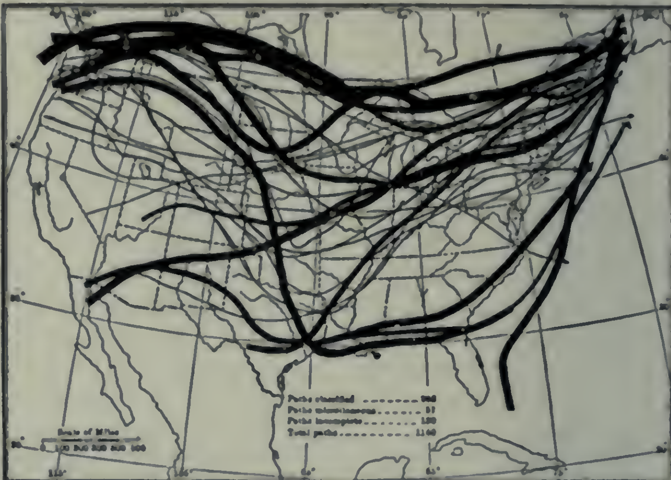
Fig. 37

approached, the ascending currents produce cirrus clouds, then cumulus and stratus clouds, and, finally, nimbus clouds with rain or snow (Fig. 32). As the centre of the low is passed, the wind rapidly changes from south and south-east to north and north-west. This brings cool weather. The rear of the cyclone becomes the front of the anticyclone. This, with its descending air currents, brings a clear sky and cool weather.

While the front of a cyclone usually brings precipitation in the winter, in the summer it generally brings only a period of hot, sultry weather, which is frequently accompanied by thunder-storms. In the summer the front of the cyclone sometimes brings a very hot wind from the south, called a *hot wave.* At the front of the anticyclone in the winter are north-west winds, which blow from the cold interior of Western Canada and sometimes extend far to the south, even reaching the Gulf States, where they produce what is called a *cold wave.* If the cold wave is accompanied by high winds and fine snow, a *blizzard* occurs. Such a storm often causes considerable loss on ranches in the western part of Canada and the United States.

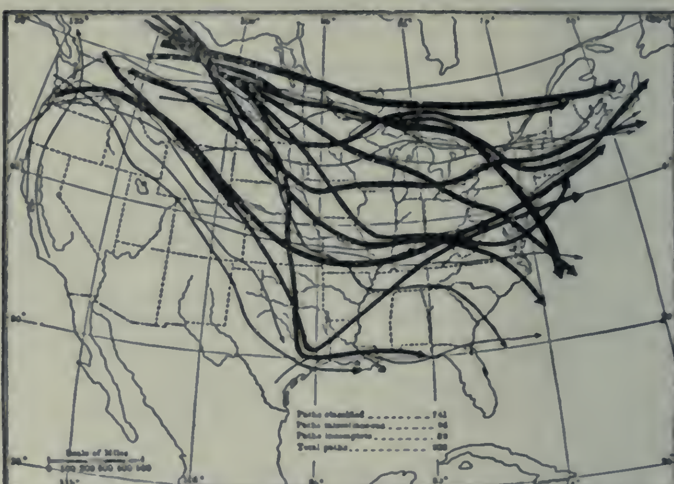
As cyclones and anticyclones follow regular tracks across the continent, it is possible, by a study of the position and the character of the cyclones and anticyclones, to forecast the weather. Figures 36 and 37 show the tracks of cyclones and anticyclones across the continent, the thickness of the line being proportional to the number of times that track is used. Figure 35 shows the position of the highs and the lows on the day succeeding the one whose highs and lows are shown in Figure 34.

55. Tropical cyclones and hurricanes.—*Hurricanes* are violent cyclonic storms that originate in or near the doldrums in certain parts of the world, and cause much



Courtesy of The Macmillan Co.

Fig. 35.—The Van Cleef system of storm tracks across Canada and the United States. Twenty-seven tracks are represented



Courtesy of The Macmillan Co.

Fig. 36.—The Van Cleef system of tracks for highs across Canada and the United States

damage on land and sea. Their general motions are similar to those of cyclones, but their size is much smaller and the violence of their winds much greater. In all parts of such storms except the centre there are torrential rains, accompanied by thunder and lightning. The centre, or eye, of the hurricane is a quiet region with little wind and a cloudless sky. In the northern hemisphere hurricanes move north-west through the trade-wind belt, bend at right angles at the horse latitudes, and move to the north-east through the belt of westerly winds (Fig. 38). Usually by the time they reach temperate regions much of their force is dissipated. Hurricanes occur in only five parts of the world (Fig. 38)—in the West Indies, in the Arabian Sea and Bay of Bengal, in the East Indies, in the Indian Ocean east of Madagascar, and east of Australia.

56. Thunder-storms.—It has been stated (Sec. 54) that in the winter, rain or snow usually occurs during the passage of a cyclone. In the summer, on the other hand, there is frequently no steady rain, but hot, sultry weather. Very frequently, however, the hot sultry weather of a cyclone is accompanied by a thunderstorm. The day has been close, quiet, and depressing, the sky is hazy, and scattered cirrus clouds are visible. Early in the afternoon cumulus clouds appear in the west, grow rapidly in size, and soon extend high in the air. Such large cumulus clouds are called *thunderheads*. Soon distant thunder is heard. A gentle wind blows toward the thunder-heads, the bottom of which is now dark, as rain is falling from it. Now the thunderheads are directly overhead, darkening the sun and relieving the oppressive closeness. Just beneath the thunder-heads is seen the narrow, turbulent, blue-drab *squall-cloud*. As the squall-cloud comes overhead, a few big drops of rain fall, or perhaps a shower of hail

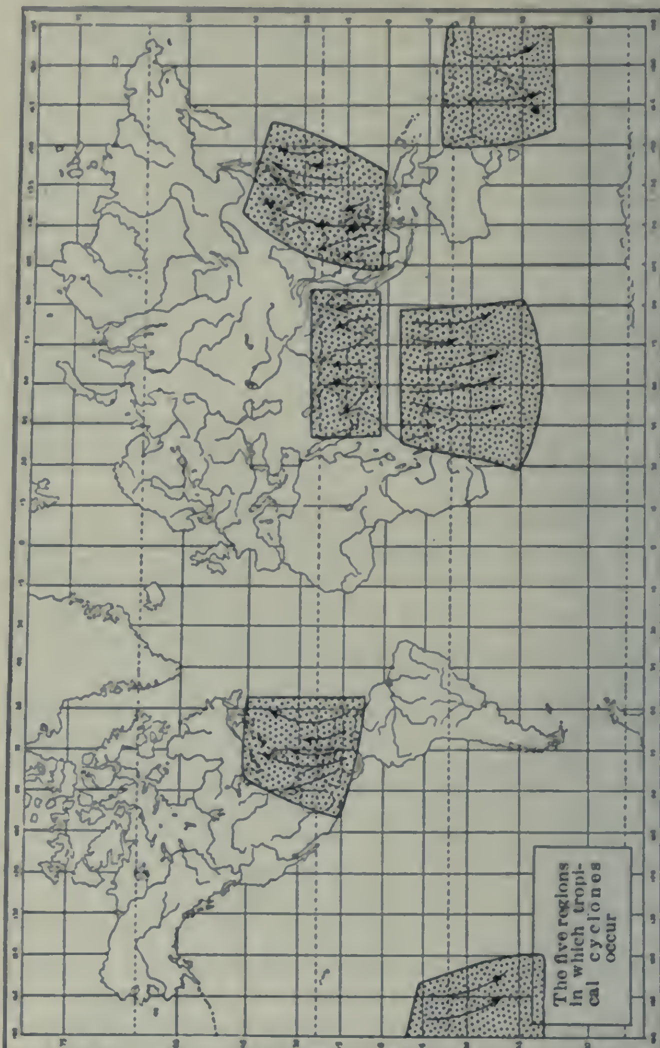


Fig. 38.—The arrows indicate the chief paths followed by the cyclones

occurs. The gentle breeze toward the storm is replaced by a violent outrush of wind from the west, called the *wind-squall*, which lasts only a few minutes. Now the rain is falling in torrents, accompanied by vivid lightning and crashes of thunder. After a short time, perhaps half an hour, the violence of the rain diminishes, the clouds begin to clear, and the thunder is heard dying away in the distance. Then the sun shines forth in a blue sky, while the thunder-heads of the storm can be seen moving forward away to the east.

Figure 39 represents the cross section of such a storm from the side. Arrows indicate the directions of the air

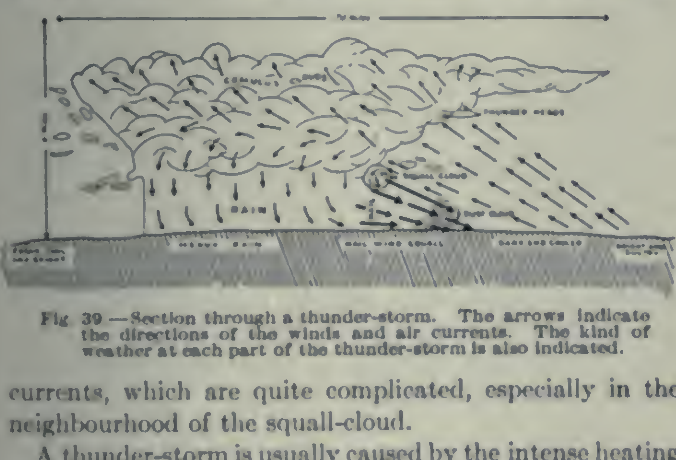


Fig. 39.—Section through a thunder-storm. The arrows indicate the directions of the winds and air currents. The kind of weather at each part of the thunder-storm is also indicated.

currents, which are quite complicated, especially in the neighbourhood of the squall-cloud.

A thunder-storm is usually caused by the intense heating of a small region, leading to a rapid ascension of masses of hot, humid air. This ascension is accompanied by a cooling of the air, causing rapid condensation, which forms cumulus clouds. A continuance of the condensation produces thunder-heads and then heavy rainfall.

57. Tornadoes.—In addition to the cyclone, 2,000 miles in diameter, and the hurricane, 200 to 500 miles in diameter, both with a vortex motion, there is the

tornado, with a diameter of a few hundred yards, which has the most violent vortex motion of all storms. Tornadoes are whirlwinds that move across the country, leaving a swath of destruction behind them. Houses are blown to pieces or lifted bodily into the air, trees are snapped off, even cars and locomotives are sometimes blown from the tracks. At a distance a tornado looks funnel-shaped (see p. 101) against the horizon. The velocity of the wind within the whirl is probably 500 miles an hour, although it has never been measured, as no instruments can withstand the violence of the wind. This spiral wind produces such centrifugal force that, in the centre of a tornado, the pressure probably drops to fifteen inches. So low is this pressure that, in the centre of a tornado, corks are blown out of bottles, and boxes and trunks explode outwards. In fact, this sudden and extreme decrease of the pressure is the cause of much of the damage produced by a tornado, for the diminished pressure on the outside of houses and other buildings causes them to explode outwards. Tornadoes are quite frequent in the Southern United States and in the Mississippi Valley, but are very rare in Canada. A violent one, however, passed through Regina in 1912, and caused great damage in that city, demolishing houses, business blocks, and churches.

Practical Exercises

Interpretation of a weather map.— Figure 40 is a weather map. Read the explanatory notes and find on the map as many of the symbols as possible. How many highs are shown on the map? How many lows? What are the pressures at the centres of (*a*) the highs, (*b*) the lows? What is the difference in pressure between the centre of the high in the New England States and that of the low over Newfoundland? Do the winds blow more

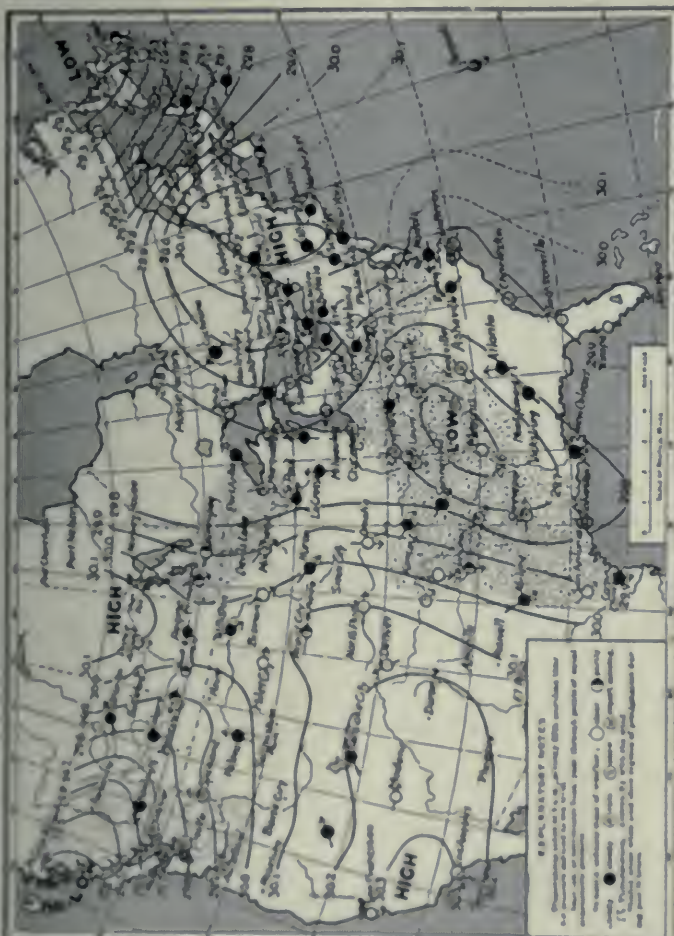


Fig. 40.—A weather map

nearly away from or toward (*a*) the highs, (*b*) the lows? If you stand with your back to the wind, is it generally deflected to your right or to your left? What is the usual direction of the wind (*a*) to the east of a low, (*b*) to the west of a low, (*c*) to the east of a high, (*d*) to the west of a high? In general, does precipitation occur in the highs or the lows? If the low shown on the map over the Mississippi Valley is moving toward Ontario, write a forecast for the Great Lakes region for March 7th under the following heads: (*a*) direction of wind, (*b*) temperature, (*c*) cloudiness and precipitation.

Weather record.—Records of the weather, without instruments, should be made at home by each pupil for at least one month, and more complete records, with instruments, should be kept at school. Pupils should rule headings as follows:

TABLE 6

Date	Hour of Observation	Temperature	Wind		Clouds		Precipitation		Remarks
			Direction	Velocity	Amt.	Kind	Amt.	Kind	
Oct 1	5 p.m.	Warm	N.E.	High	Clear	Cirrus	None	None	Heavy Dew

The observations should be made at the same hour each day. The following descriptive words should be used:

Temperature.—Very cold, cold, cool, mild, warm, hot. very hot.

Wind direction.—North, north-east, east, etc.

Wind velocity.—Calm (no wind), light (moving leaves of trees), moderate (moving branches of trees), brisk (swaying branches of trees), high (swaying trees, moving twigs on the ground), gale (breaking small branches from trees).

Amount of cloud.—Clear (less than three-tenths cloudy), fair (between three-tenths and seven-tenths cloudy), and cloudy (more than seven-tenths cloudy).

Kind of cloud.—Cirrus, stratus, cumulus, nimbus, and combinations of these (Sec. 35).

Amount of rainfall.—Pupils should state for how many hours it rained and whether the rainfall was heavy or light.

The school record should be kept for two months, one pupil being assigned for each week to read the thermometer, barometer, etc. For the school record the following table should be filled out:

TABLE 7

Date	Hour	Pressure	Temperature			Precipitation		Wind		Clouds
			Max	Min	Mean	Kind	Amt	Direction	Force	
Jan 3	4 15 a.m.	29 56	35°	14°	26°	Snow	4 in	N E	gale	7/10

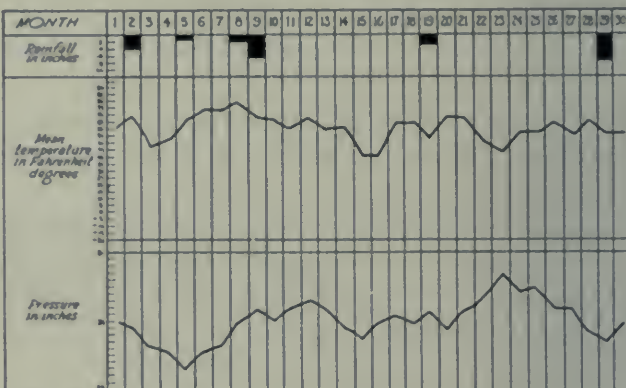
From the school record, which should be posted on the bulletin board, each pupil should make a graphical record such as the following:

By a study of all the weather records the pupils should find the following relations:

Temperature and wind. — Direction of the warmest winds, of the coldest winds.

Temperature and cloudiness. —In general, are cloudy or clear days the colder?

TABLE 8



Cloudiness and precipitation. — Are clouds necessary for precipitation? What kinds of clouds? Must the sky be entirely overcast? Does an overcast sky always bring precipitation? What is the relation between the amount of dew and the amount of cloudiness?

Wind and precipitation. — What winds bring rain in the summer? In the spring and the autumn? What winds bring snow? What winds accompany thunderstorms? Compare the winds before and after a rainstorm.

Temperature and precipitation. — Is the temperature higher or lower after rain? Is this relationship the same in winter as in summer?

QUESTIONS

1. If the centre of a cyclone moves from west to east, describe the changes in the direction of the wind at a place just south of its path. Describe the changes in the direction of the wind at a place just north of its path.

2. Find in the dictionary the meaning of veering and backing winds, and state, from Question 1, the condition under which these winds occur.

3. What kind of weather does a falling barometer indicate? A rising barometer?

4. Why do rain and cloudiness usually occur at a place as the centre of a cyclone passes over it?

Fig. 41 (a) —Tornado

CHAPTER VII

CLIMATE

Classification of Climates

58. Meaning of climate.—By weather conditions are meant atmospheric conditions with respect to temperature, humidity, and pressure, over comparatively short periods of time. The averages of all the weather conditions for a long period of time give the data for describing the *climate.* In fact, climate may be defined as the average state of the weather. Some weather conditions are more important than others in determining climate. Of chief importance are those that have a direct and powerful influence upon plant and animal life. For instance, temperature, rainfall, winds, and cloudiness are essential elements of a climate, but pressure, which is so fundamental in determining weather, receives little attention as an element of climate, since it has little direct effect on plant and animal life.

Many physical conditions affect the climate of a region. Latitude, altitude, proximity to large bodies of water, direction of winds and ocean currents, and relative amounts of land and water are some of the chief physical factors. As these factors are variously combined, they cause a great variety of climate in different parts of the world. We may, however, distinguish four main types of climate—*oceanic*, *continental*, *desert*, and *mountain*.

59. Oceanic climate.—When proximity to the ocean or to any large body of water is the determining factor, an *oceanic climate* is produced. As the ocean warms but slightly in the summer and cools very little in the

winter, it tends to equalize the summer and winter temperatures of the regions affected by proximity to it. Therefore lands having an oceanic climate have cold springs, warm autumns, cool summers, and mild winters. In these regions there is much cloudy weather and a heavy rainfall, the greater part of which occurs in the winter when the land is cooler than the water. Not all coasts have oceanic climates, but only those on the leeward side of the ocean. The coast of British Columbia has a typical oceanic climate, since the winds blow over it from the Pacific. Eastern Canada has not an oceanic climate, since its prevailing winds come over land from the west. Therefore its climate is more like that of the interior of the continent.

60. Continental climate.—At the centre of continents, as in Central Canada and Central Asia, the influence of the ocean is absent, and a *continental climate* results. The most characteristic feature of a continental climate is its extremes of temperature, due to the rapidity with which the land is heated and cooled. Regions with such a climate have hot summers, cold winters, and a great difference between the temperatures of day and night. A clear sky and small precipitation, which is greater in the summer than in the winter, are also characteristic of this type of climate. Usually the velocity of the wind is less in continental interiors than on the coasts, and calms are more frequent. The clear sky, the low humidity of the air, and the lack of wind during the coldest weather ameliorate the low winter temperatures of such regions.

61. Desert climate.—Deserts have an extreme continental climate. Clouds seldom darken the sky, and the precipitation is so small that vegetation is very scanty. Owing to the clear sky and the dry air the daily range of temperature is very great. The sand, although exceedingly hot during the day, cools rapidly through

the night and becomes comparatively cold before morning. As the intensely heated air rises in convection currents during the day, the surrounding air rushes rapidly in, causing violent sand-storms. The nights are usually calm.

62. Mountain climate.—We have already learned that the temperature decreases as higher altitudes are reached. Accordingly, all the degrees of temperature experienced in passing along the surface of the earth from the equator to the polar regions are also experienced in ascending a single high mountain, even though it is situated near the equator.

In mountainous districts, if the sky is clear, winds blow up the valleys toward the peaks during the day. These *valley breezes*, as they are called, are caused in the following way. During the day the air along the slopes of the mountains becomes heated, and, consequently, its pressure becomes less than that of the adjacent air at the same level. This adjacent air at a greater pressure forces the warmer air up the slopes, and so a breeze blowing up the mountain results. During the night, however, the slopes rapidly cool by radiation, and the air near them cools also, and soon is at a higher pressure than the adjacent air at the same level. The cooler air at a greater pressure tends to drop down below the warmer air at a less pressure, and so a steady stream of air flows down the slopes of the mountains during the night. These winds are called *mountain breezes*.

Precipitation on the side of a mountain increases with the altitude up to about 6,000 or 7,000 feet, but beyond this height it decreases. The precipitation is much greater on the windward than on the leeward side of mountains. For example, while the western slopes of the mountain ranges in British Columbia have a very heavy precipitation, the eastern slopes are very dry.

Climatic Zones

63. Classification.—Many scientists have attempted to divide the earth into climatic zones. The very earliest of Greek scholars made a division of the earth's surface into the torrid, temperate, and frigid zones. This division has been retained up to the present time, is still the most popular of all, and, despite certain disadvantages, will be followed in this book. Since it is based entirely on the relative amounts of sunlight received by the different parts of the earth, without taking other factors into account, it brings into the same zones regions with very different climates and separates regions with very similar climates.

Figure 41 illustrates a division into temperature zones, made by Professor A. Supan. The hot belt includes all parts having a mean temperature higher than 68°F. The boundaries of this belt coincide closely with the polar limits of the trade-winds. They also mark the polar limits of the growth of palms. The temperate belts are separated from the polar caps by the isotherm of 50°F. for the warmest month. This isotherm also marks the polar limit of forest trees and cereal crops. It will be noticed that the hot belt is wider over the continents than over the oceans, and that the north temperate belt is much wider than the south temperate belt. This latter difference is mainly due to the large land masses of the northern hemisphere. As they warm rapidly during the summer, they tend to raise to a high summer temperature regions far to the north, while the vast oceans of the southern hemisphere have just the opposite effect upon regions far to the south.

The Torrid Zone

64. General.—The climate within the tropics is simple and uniform. There is no uncertainty regarding the next

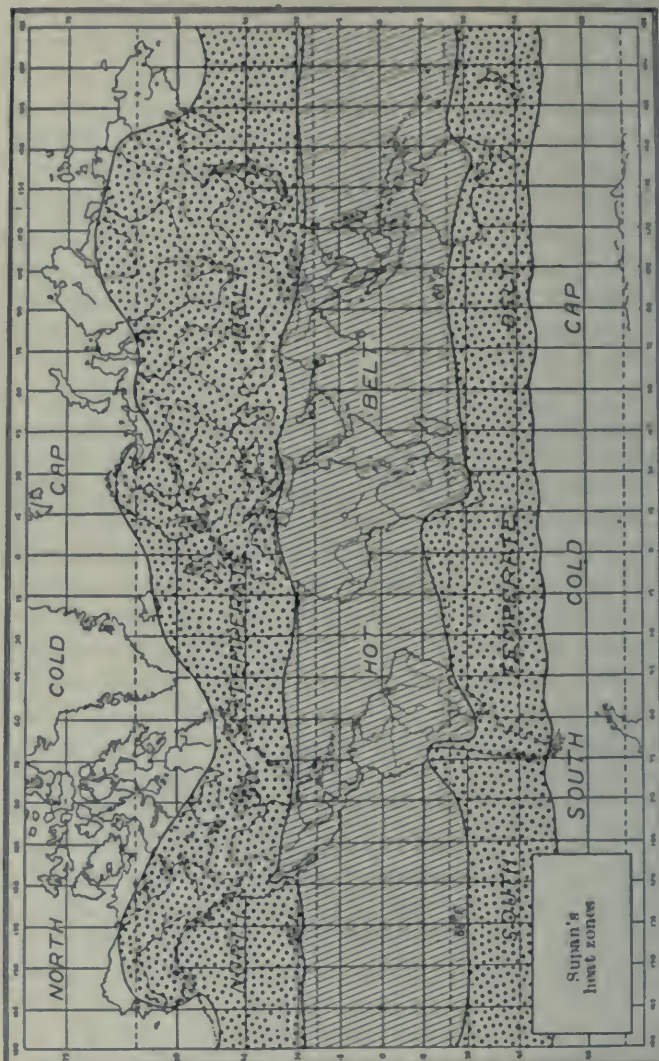


Fig. 41.—The boundaries of the hot belt are the annual isotherms of 68°F. The polar boundaries of the temperate belts are the isotherms of 50°F., for the warmest month

day's weather, from day to day, for the temperature, rainfall, and cloudiness vary little on successive days. The changes of weather conditions are exceedingly regular, except when a tropical cyclone comes with startling suddenness, spreading devastation in its wake (Sec. 55). The temperature is always high; in fact, the annual isotherm of 80°F. incloses most of the land area. In most regions within the tropics, the range of temperature throughout the year is less than 10°F. Indeed, over much of this area the annual range is less than 5°F., being much smaller than the daily range in the same region. Only at high altitudes does the temperature ever reach the freezing-point. There is no winter, as we understand the term. The seasons are regulated by the rainfall and not by temperature. The rains which occur during the summer fall daily at about the same hour in torrential downpours, accompanied by violent thunder and lightning. So regular are they in this respect that ladies in Rio de Janeiro state on invitations to afternoon receptions whether the guests are to come before or after the rain. In coastal regions breezes blow from the sea during the day with great regularity, and help materially to make the sultry weather tolerable.

The character of the inhabitants of tropical countries depends partly upon the climate. The hot, humid air of the coastal districts is enervating, so that severe or long-continued physical or mental effort is impossible. In the deserts, where food and clothing are harder to obtain, and where the cool nights have a tonic effect, the people are somewhat more energetic and capable. Rarely has a great nation been developed within the tropics.

There are three well-marked climatic divisions in the torrid zone—the *equatorial region*, the *trade-wind belt*, and the *monsoon region*.

65. The equatorial region.—The doldrums, as we have seen (Sec. 50), are characterized by ascending air currents, with cloudy skies, humid air, and heavy rainfall. As the doldrums move northward or southward toward the tropics with the vertical rays of the sun, they bring a rainy season to the areas affected. As a result, in a belt extending eight or ten degrees on each side of the equator, there are two rainy seasons, coincident with the passing of the vertical rays of the sun, and two intervening dry seasons (Fig. 42). These double seasons occur in Central Africa, Equatorial South America, and in many tropical islands (Fig. 43). As the dry seasons are short and never entirely rainless, these regions, especially in coastal districts, are covered by dense, tropical forests. On each side of this equatorial belt is a region in which the movement of the doldrums to the tropic is followed so closely by its movement toward the equator that the two rainy seasons blend into a single one (Fig. 43). For the rest of the year these belts are under the influence of the trade-winds. This, as we shall see in the next Section, causes a dry season. Accordingly, these belts have one rainy and one dry season. During the rainy season vegetation is most luxuriant, but during the hot, dry season it withers very rapidly. The leaves fall from the trees, while the soil hardens and cracks with the heat. Nowhere else in the world is there such a contrast in the appearance of nature during two successive seasons. Venezuela, Mexico, southern Brazil, the Sudan, Abyssinia, Upper Egypt, as well as Hawaii and many other tropical islands have seasons of this type (Fig. 43).

66. The trade-wind belt.—In the regions from 20° to 30° north and south of the equator, the trade-winds control the climate. Since these winds blow from cooler to warmer regions, their temperature rises as they progress. Consequently, they are drying winds. If they

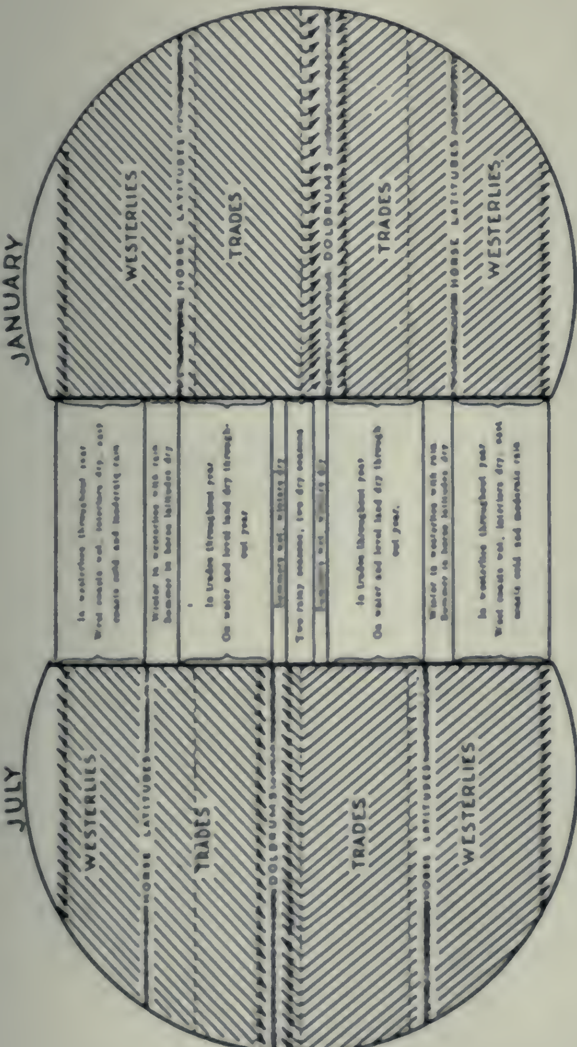


Fig. 42.—Climates in relation to the winds and calms

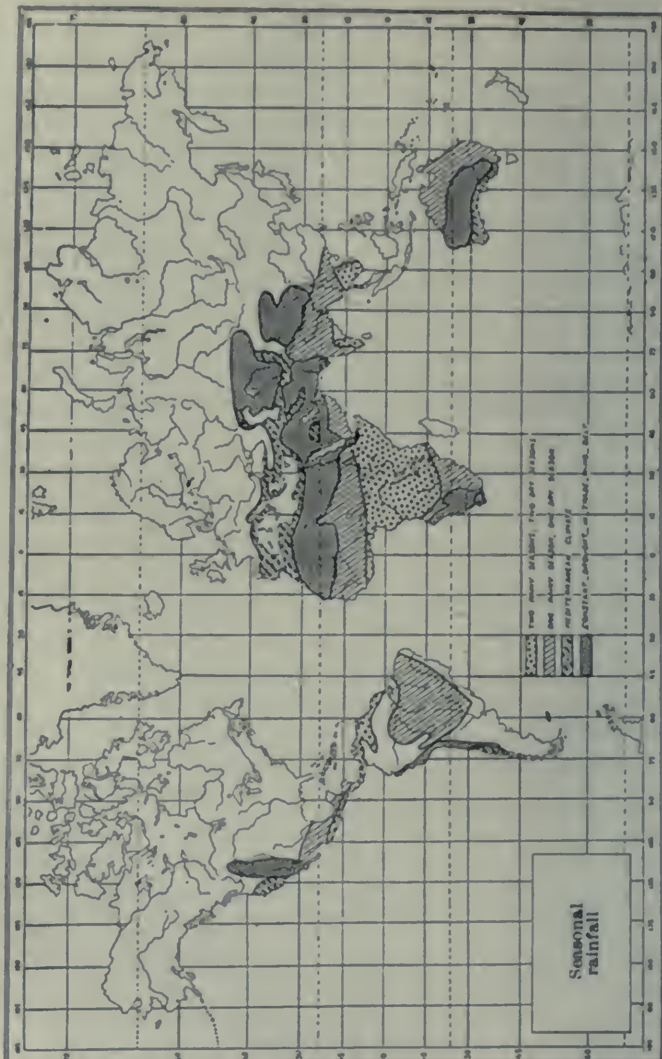


Fig. 43.

blow over the ocean or over lowlands, little or no rain falls, and so lowlands in the trade-wind belt are mainly desert lands. Most of the great deserts of the world are in the trade-wind belt (Fig. 43—black shading). For example, the deserts of Arabia, Persia, and Lower California are in the northern trade-wind belt, while the deserts of Chile, South Africa, and Australia are in the southern trade-wind belt. On the other hand, if the trade-winds strike bold coasts or plateaus or mountains, they bring a heavy rainfall. Many of the East and West Indies, the Philippines, Ceylon, Madagascar, the east coasts of Guiana, Central America, Mexico, south-eastern Brazil, south-eastern Africa, and eastern Australia, all have heavy precipitation owing to the highlands in the path of the trade-winds. While these regions have rainfall at all seasons, the maximum precipitation comes in the winter.

67. The monsoon region.—The influence of the monsoons is most marked in India and south-eastern Asia. Over this region the south-west monsoon blows from the end of April until October. This warm, humid wind causes abundant precipitation, especially on the windward sides of mountains. On the windward slopes of the mountains of Bengal occurs the heaviest rainfall in the world. During the winter months the north-east monsoon blows out from the dry plains of Central Asia and brings cool, dry weather to India. Besides the rainy season and the dry winter, there is also a hot season in India. It occurs during the early spring, when the north-east wind has become heated and blows south as a hot, scorching wind. Monsoons also occur in northern Australia and the adjoining East Indies (Fig. 30).

The Temperate Zones

68. General.—Unlike the torrid zone, the temperate

zones are marked by frequent changes of weather from day to day or even from hour to hour. In the north temperate zone the range of temperature during a single day is greater than in any other part of the world. This zone lies in the belt of the westerlies, which are much less regular than the trade-winds. They blow more strongly in the winter than in the summer, and are much interrupted by cyclonic storms.

The rainfall of the temperate zones is fairly abundant over the ocean and over much of the land. Bold west coasts beyond latitude 40° have heavy rainfall. The seasons in these zones are classified according to temperature as summer, autumn, winter, and spring. At the polar limits of the zones the transition from summer to winter and from winter to summer is so sudden that spring and autumn are very brief. The margins of the temperate zones toward the tropics have climates so distinct that they will be described separately as the *sub-tropical belts.*

69. The sub-tropical belts.—These are in the horse latitudes during the summer, but the retreat of the sun toward the equator brings them under the influence of the westerlies during the winter (Fig. 30). The northern sub-tropical belt lies between 28° and 40° north latitude, and the southern sub-tropical belt occupies the corresponding region in the southern hemisphere. Since these belts are in the horse latitudes during the summer, the air is warm, dry, and cloudless during this season. Since they are in the belt of the westerlies during the winter, they are then cooler, with westerly winds and a considerable rainfall. On account of the clear sky, even temperature, and moderate rainfall, these belts possess some of the chief health resorts of the world. As the rains come in winter, the soil usually requires irrigation. The conditions described above are usually limited to

the western sides of the continents. Southern California, central Chile, the southern part of the west coast of South Africa, and south-west Australia are in these belts (Fig. 43). The whole region around the Mediterranean Sea, as well as the region extending eastward through Syria and Mesopotamia to Persia, has a climate of this character. Since the largest and most important area in the world with such a climate is that surrounding the Mediterranean Sea, this type of climate is usually called a *Mediterranean climate.*

70. The south temperate zone.—As the continents are very narrow in the south temperate zone, the climate there is more uniform than in the north temperate zone. The range of temperature is comparatively small, the west winds are strong and steady, and the seasons are uniform. While the climatic conditions in the south temperate zone are steadier than in the north temperate zone, the former is more subject to cyclonic storms than is the latter. These are less frequent in summer than in winter. This zone is one of the most healthful regions in the world. Patagonia and some of the southern islands are within its boundaries.

71. The north temperate zone.—Since in this zone the westerly winds blow from the oceans to the west coasts, the latter have cool summers and mild winters. The rainfall is abundant, reaching a maximum in the autumn and the winter, when the westerlies are strongest. Where high mountains are near the coast, as in British Columbia, the rainfall is very heavy, but where there are no high elevations, as in certain parts of the west coast of Ireland, the rainfall is not so excessive.

In the continental interiors the prevailing winds are from the west. As they have already blown over the land for a considerable distance, the moderating influence of the ocean is lost. Accordingly, in the continental

interiors of the north temperate zone are found the most extreme temperatures in the world. The central part of Canada and of the United States is a good example of such a region. The winters are clear, dry, and very cold, the summers are warm, and the heaviest precipitation occurs during this season. Since the westerlies lose nearly all their moisture in ascending the western slopes of the ranges of the Rocky Mountain system, they reach the eastern slopes as dry winds. As they flow down the eastern side of the mountains, the pressure continually increases, and, consequently, the air becomes warmer. These warm, dry winds sweeping over the plains absorb moisture very rapidly, so that the area in the lee of the mountains is very dry. At the same time, these *Chinook winds*, as they are called, moderate the winter temperatures to a marked extent. In Eurasia the amount of precipitation steadily decreases eastward, Ireland having a heavier rainfall than England, and England having a heavier rainfall than Germany. In central Siberia the precipitation reaches a minimum. The continental interior climate is exhibited most perfectly in Siberia, since that country is the centre of the greatest land mass in the world. One part of it has an annual range of temperature of more than 120°F. Since the summer is hot and the rainfall is most abundant during this season, agriculture can be carried on in continental interiors even in very high latitudes, as is the case in Canada and Siberia.

Although the east coasts in the temperate zone are in proximity to the ocean, their climate is influenced by the continental interior to a greater extent than by the ocean, since the prevailing winds are from the west. Consequently, warm summers and cold winters are typical of east coasts in this zone, although the seasons are not so extreme as in the interior. Cyclones and anticyclones

determine their weather (Sec. 54). Since the easterly winds at the front of a cyclone blow from the ocean, they bring rain. Therefore the amount of precipitation increases from the interior of a continent to the east coast. In Canada, for example, Quebec has heavier precipitation than Ontario, while the rainfall in the Maritime Provinces is still more copious.

The Frigid Zones

72. General.—The westerlies do not extend far beyond the polar circles. The parts of the frigid zones nearest the polar circles have a climate similar to that of the colder parts of the temperate zones. In polar regions there is no warm season, and the winters are very cold. As cold air never contains much moisture, the precipitation is light. It consists largely of fine, dry snow, though some rain falls even in the highest latitudes. As there is little melting and evaporation, even the small amount of snow that falls from time to time tends to accumulate. There are no trees, and other vegetation is of the scantiest kind. There are few permanent settlements within the Arctic Circle.

QUESTIONS

1. The following table gives the mean monthly temperatures in degrees Fahrenheit for Vancouver, Winnipeg, Toronto, and Halifax:

	J	F	M	A	M	J	J	A	S	O	N	D
Vancouver	35	38	42	47	54	58	66	62	56	49	42	29
Winnipeg	5	1	14	37	52	62	66	63	53	40	20	5
Toronto....	22	22	29	41	53	63	68	67	59	47	36	26
Halifax	27	24	30	39	49	58	65	65	58	49	38	28

Draw temperature graphs for each city and explain the chief difference between the graphs.

Has Toronto or Halifax the later spring? Which has the warmer autumn?

2. The following table gives the mean monthly precipitation for Vancouver, Winnipeg, Toronto, and Halifax:

Month	Vancouver	Winnipeg	Toronto	Halifax
Jan.	8.6	0.8	2.9	5.8
Feb.	6.2	0.9	3.6	4.7
Mar.	4.5	1.2	2.7	5.3
Apr.	3.0	1.5	2.4	4.4
May	3.6	2.4	3.0	4.2
June	2.8	3.6	2.8	3.8
July	1.3	3.2	3.0	3.9
Aug.	1.7	2.5	2.8	4.4
Sept.	4.3	2.1	3.2	3.8
Oct.	5.7	1.7	2.4	5.5
Nov.	11.3	1.1	2.9	5.6
Dec.	7.6	0.9	2.8	5.4
Totals	60.57	21.69	34.37	58.81

Draw precipitation graphs for each city. What cities have the heaviest precipitation in winter? In summer? In what city is the precipitation most evenly distributed throughout the year? Give reasons in each case. What type of precipitation is most valuable for agriculture? Why is Winnipeg, with such a light rainfall, the centre of an excellent agricultural region?

3. Which has the more cloudy weather, Winnipeg or Vancouver? Halifax or Toronto?

CHAPTER VIII

THE OCEANS

Preliminary Experimental Work

(1) To study the properties of salt water.—

Make a saturated solution of common salt. Add to it ten times its volume of water. This solution has very nearly the composition of sea water. Taste the solution. Find its specific gravity by means of a specific-gravity bottle. Place a thermometer in a test-tube of the salt water, and surround the test-tube with a freezing mixture of salt and snow, or leave it outside the window on a cold winter day until ice begins to form. At what temperature does sea water freeze? Let a vessel of the salt water remain out-of-doors on a cold winter day until a thin layer of ice forms on its surface. After washing off any adhering water, melt a piece of the ice and compare, by tasting, the salinity of the melted ice with that of the original salt water.

(2) To study a bathymetrical chart of the oceans.—

Figure 44 is a bathymetrical (Greek—*bathos*, depth) chart of the oceans. Those parts of the oceans which adjoin the continents and are less than 100 fathoms deep are called *continental shelves*. Where, in the North Atlantic, are the continental shelves very wide? Why are these wide shelves the great fishing-grounds of the world? What inland waters connected with the Atlantic are to a large extent less than 100 fathoms deep? What is the greatest depth of water on the ridge between

Fig. 44.—Bathymetrical chart of the oceans   *Courtesy of The Macmillan Co.*

Greenland and the north of Scotland? Is there any obstruction to prevent the cold water at the bottom of the Norwegian Sea (between Norway and Iceland) from mixing with the water of the North Atlantic? Why are the deep-sea animals of the Norwegian Sea for the most part different from those of the adjoining North Atlantic? Give a possible explanation of the fact that the animals of northern Canada are very similar to those of northern Europe. Is there any obstruction to the cold bottom water of the Antarctic regions creeping north along the bottom of the Atlantic? If the bottom water of the Atlantic comes from the Antarctic regions, would it be colder (*a*) at 50° south latitude or at the equator, (*b*) at the equator or at 50° north latitude? Observe the position of the Mid-Atlantic Ridge. What is the depth of water over the greater part of it? Between 40° and 45° north latitude it widens east and west. Why is this expansion called the telegraphic plateau? What islands are situated on the Mid-Atlantic Ridge? Where is there a break in the Ridge? What is the depth of water on each side of the Mid-Atlantic Ridge? What proportion of the Atlantic Ocean is between 2,000 and 3,000 fathoms deep? Regions having a depth of more than 3,000 fathoms are called *deeps*. How many deeps are there in the Atlantic? Where is the most extensive deep? At what point is the Atlantic more than 4,000 fathoms deep? How does the continental shelf along the west coast of America compare in width with that along the east coast of America? Compare the proportion of the Pacific Ocean that is between 2,000 and 3,000 fathoms deep with the proportion of the Atlantic that is between the same depths. Compare the number of islands in the Pacific Ocean with the number in the Atlantic. How many deeps are there in the Pacific Ocean? Compare the shallows, ridges,

and deeps of the Indian Ocean with those of the Atlantic and Pacific Oceans.

Depths and Deposits of the Oceans

73. Methods of investigating the ocean.—For many centuries all but the coastal waters of the oceans was a mystery. Even the early European navigators, such as Columbus, Magellan, Drake, and Cook, contributed only to the knowledge of the extent of the oceans and of the character of their surface waters. Not until about 1850 was a real attempt made to study the oceans scientifically. In that year M. F. Maury, the great American geographer, endeavoured to sound their depths. Twenty years later a

Fig. 45.—H.M.S. *Challenger* after collision with an iceberg, Feb. 24th, 1874

solid basis for the future study of the oceans was laid by the deep-sea explorations of the British ship, *Challenger* (Fig. 45). Between 1872 and 1876 this ship traversed all the oceans, sounded their depths, collected plants and animals from all levels of the water, and made a complete examination of the temperature, salinity, and other

properties of sea water. Under the direction of Sir John Murray, a Canadian (1841-1914), the results of this expedition were issued in fifty magnificent volumes, prepared and wonderfully illustrated by the greatest scientists of the world.

In no field of scientific endeavour has greater skill, ingenuity, and inventiveness been shown. To sound the ocean's greatest depths from the deck of a ship as it rolls in the swells and drifts in the currents is no mean achievement. Yet that has been accomplished, and specimens of the deposits on the bottom have been brought up from a depth of almost six miles. A number of nets, all attached to a single line, can be dragged through the ocean at different depths. The nets can be closed while descending and ascending, in order that the organisms of only one level may be contained in each net (Fig. 46). Empty water-bottles can be lowered to any depth, then opened to be filled with the sea water at that level, then closed and brought to the surface. In this way may be procured specimens of the water of any level unmixed with that of any other level (Fig. 47). These bottles can be so perfectly insulated that, although it may require an hour or more to raise them from a depth of four or five miles, the temperature of the contents does not change by the one-hundredth part of a degree during the operation. Although it is impossible to anchor in the deepest sea, instruments are in use by which the strength of the current can be measured and its direction determined, not

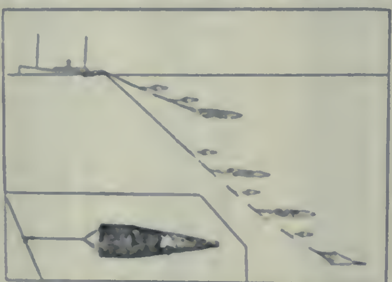


Fig. 46.—Nets for capturing animals at different depths

only at the surface, but also at all depths. As the pressure at great depths may be more than six tons on every square inch, the difficulty of manufacturing instruments capable of withstanding such tremendous pressures makes their successful construction still more marvellous. Figures 48, 49, and 50 show a trawl, a dredge, and a sounding instrument used in deep-sea investigations.

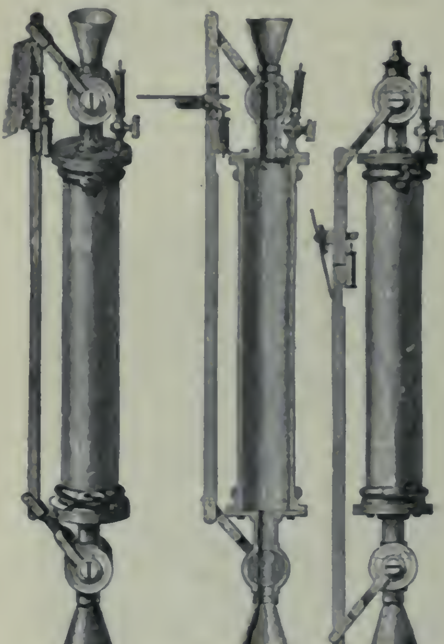


Fig. 47.—Stop-cock water-bottle, in section, closed and open

Fig. 48.—The beam trawl used in deep-sea work

74. Uses of the ocean.—The rapid improvement in the construction of ships has completely changed man's attitude toward the sea. Formerly the sea was considered a great barrier, separating the peoples of different lands. Now it has become a highway, bringing into

communication lands far separated. In some cases the peoples on opposite sides of an ocean have better and cheaper communication with one another than those on the opposite sides of a continent. The sea is the chief source of the world's supply of food fishes, and many millions of dollars' worth of fish are taken from its waters annually. The influence of the ocean upon climate is

Fig. 49 —The dredge

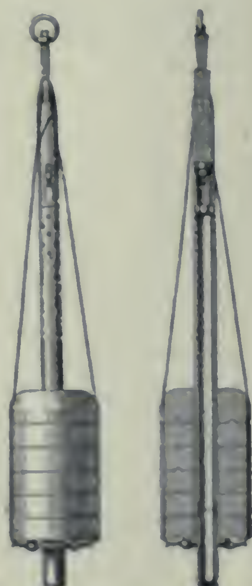


Fig. 50 —Baillie sounding machine

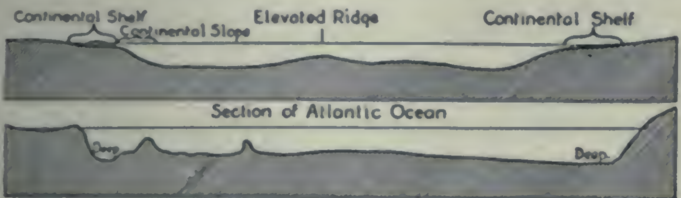
still more important. Its currents transport great quantities of heat from equatorial regions toward the poles, so that the climate of many regions in high latitudes is moderated. Many areas that otherwise

would be as bleak and barren as Labrador, produce cereals in abundance, as a result of the beneficent breezes from the ocean. Cold currents from the polar seas also help to moderate the heat of the tropics. Furthermore, almost all the rain that is so necessary for plant growth is formed from water vapour that rises from the ocean.

75. Extent of the oceans.—The oceans occupy about seventy-one per cent, or considerably more than two-thirds, of the earth's surface. They are divided by the continental masses into four grand divisions, called the Atlantic, Pacific, Indian, and Arctic Oceans. The first three of these unite in the south. Formerly the south polar region was supposed to be occupied by a great body of water, known as the Antarctic Ocean. But now it is known that this region is occupied by a continental mass called the Antarctic Continent, or Antarctica. Accordingly, the Atlantic, Pacific, and Indian Oceans are considered to extend to the Antarctic Continent, and the name Antarctic Ocean is no longer used.

76. Relief of the ocean floor.—If the bottom of the ocean were levelled, the depth of the water would be everywhere more than two miles. On the other hand, if the land were all levelled, its height above the sea-level would be considerably less than half a mile. The bottom of the ocean is much less diversified than the surface of the land. In fact, it is generally flatter than the most level prairie. Figure 51 represents sections across the Atlantic and Pacific Oceans. Figure 44 is a map of the oceans, with different shades to represent the different depths. The bottom of the North Atlantic slopes away from the continents very gradually at first (Fig. 51), so that there is a large area along the coasts of the continents of America and Europe in which the water is comparatively shallow. The shallower parts of these continental shelves are called *banks*. The banks of the

Atlantic are the greatest fishing-grounds of the world. At the outer edge of the continental shelf, the slope of the bottom is much steeper. This part of the bottom is called the *continental slope.* The most striking feature of the bottom of the Atlantic is an elevated ridge over



Section of Pacific Ocean

Fig. 51

which the water is between 1,000 and 2,000 fathoms deep. It runs in the form of an *S* throughout the length of the ocean, dividing it into an eastern and a western part. An elevated ridge, over which the water is less than 500 fathoms deep, runs from Greenland through Iceland to Scotland. This separates the Arctic Ocean from the Atlantic Ocean and prevents the mixing of the bottom waters of these two bodies of water. The most extensive deep in the Atlantic Ocean is situated north of the West Indies and is called the Nares Deep. In the southern part of this hollow, just north of Porto Rico, is the deepest sounding yet obtained in the Atlantic Ocean. At this point the water is over five miles in depth. Deeps are avoided in laying cables, in order to prevent breakage and to have the cables more accessible for repairs.

The eastern margin of the Pacific Ocean (Fig. 51) has a very steep slope; in fact, several deeps are very close to the coast of South America. In this respect it is in marked contrast with the margin of the Atlantic Ocean on the opposite coast of America. The Pacific, unlike the Atlantic, has many scattered volcanic and coral

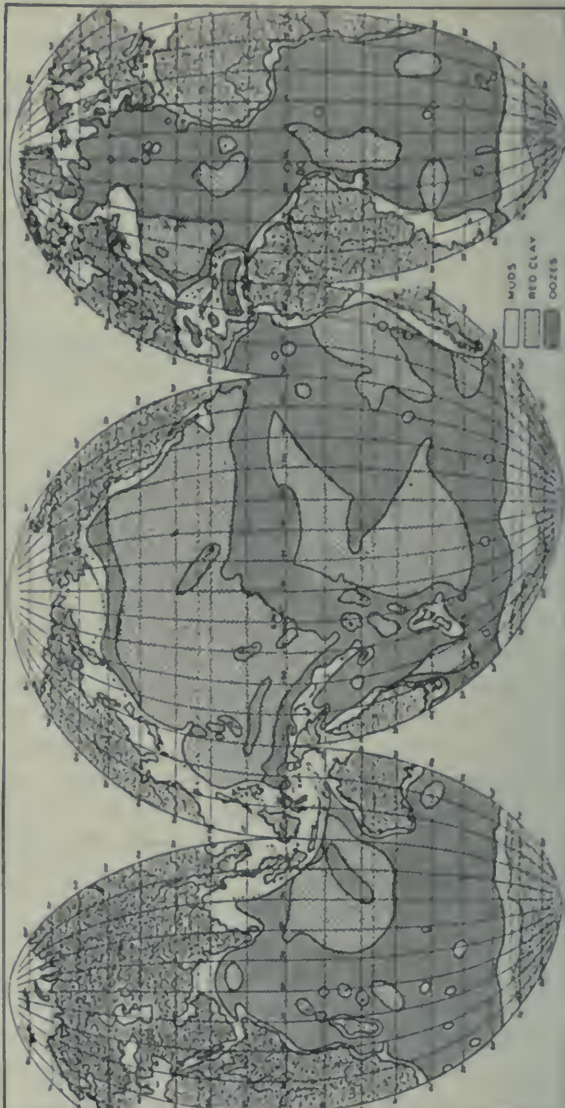


Fig. 52.—Deep-sea deposits
The World on the homalographic projection for the oceans

islands rising quite abruptly from great depths. In the Pacific are numerous deeps, the most notable of which are the Tuscarora Deep off Japan and the Aldrich Deep east of Australia. Along the western margins of both these deeps are trenches over 4,000 fathoms in depth. The greatest depth found in any of the oceans was recently discovered just east of the Philippines. At this point the water is 5,348 fathoms, or more than six miles deep.

77. Deep-sea deposits.—The materials found on the bottom of the ocean near the coast consist largely of sand, clay, and organic matter washed down by rivers. The continental shelf is covered with such deposits. Beyond the continental shelf are deposits, called *muds* (Fig. 52). Blue mud is the kind of most common occurrence. Sometimes, however, a green or red mud is found. All these deposits come largely from the land.

In greater depths far from the land occur the *oozes*. These are very fine, soft deposits, which contain little or no land sediment. The oozes are composed largely of the shells of marine animals and plants. Figure 53 represents a sample of one of these organic oozes as seen under the microscope. At the greatest depths the ocean floor is covered with a fine-grained red

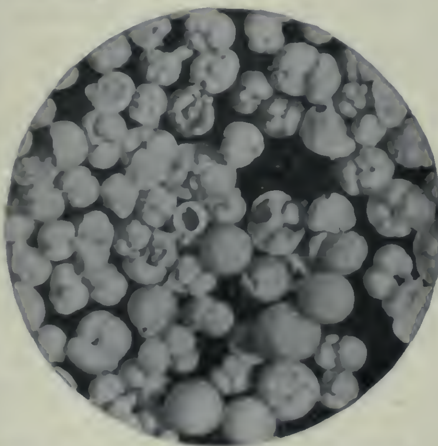


Fig. 53.—Coarse globigerina ooze, magnified twelve diameters

clay, the most wide-spread of all deep-sea deposits. This red clay is largely a product of the decomposition of volcanic and meteoric dust. It frequently contains the ear bones of whales and the teeth of sharks in great profusion, but no shells are found in it. As microscopic organisms swarm in the waters above these areas covered by red clay, it is thought that the lime of their shells must be dissolved by the sea water, the solvent power of which is increased at these great depths by the enormous pressure.

As no rocks have ever been discovered with a composition similar to that of the red clay found in the deep-sea deposits, it is considered probable that the continents have never formed the beds of ocean deeps. While in some cases lands have been depressed below the sea, and while in others the bottoms of seas adjacent to the land have been raised above the water, the continents as wholes have never been depressed to form the beds of oceans, nor have the ocean beds ever been elevated to form continents.

Physical Properties of Sea Water

78. Temperature.—The heating of the water of the oceans is largely due to solar radiation. The effect of this is greatest upon the surface water. The surface temperature generally decreases with distance from the equator, but ocean currents cause the surface isotherms of the water to run very irregularly. The annual range of temperature of the surface water is not nearly so great as that of the land. The range at the equator is only 4°F., and at 40° north latitude, where it is greatest, only 18.4°F., whereas the range over the land in parts of Siberia is over 120°F.

The temperature of the water of the ocean also decreases with depth. Figure 54 shows by a graph the decrease

in the South Atlantic Ocean (a continuous line *A*). While the decrease is rapid to a depth of 600 fathoms, beyond that it is very slow, but continues almost to the bottom. The temperature of the water in all parts of the oceans

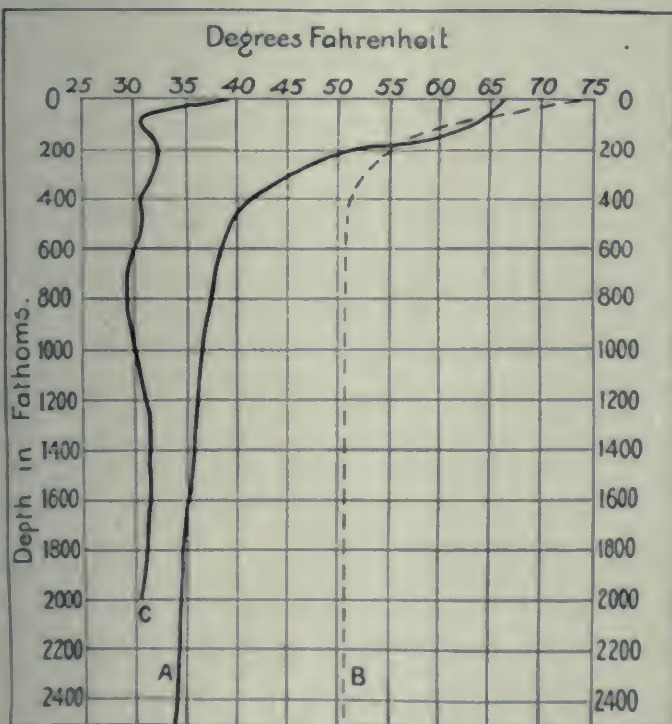


Fig. 54.—Graphs of temperature of ocean water at different depths
A—Normal change from a sounding in the South Atlantic Ocean
B—Change in an inland sea *C*—Summer condition of Polar Sea

decreases with the depth. Recently, however, it has been observed that at great depths there appears to be a slight rise of temperature. Since liquids, like gases, become warmer when they are compressed, this rise of temperature is probably due, partly to a slight compression of the

water caused by the great pressure, and partly to a slight radiation of heat from the interior of the earth. The amount of decrease for the first few hundred fathoms is greater at the equator than in higher latitudes. Therefore the temperature of the water at the equator at considerable depths is not much different from the temperature at the same depth in higher latitudes, although the surface water is much warmer.

As both the Atlantic and Pacific Oceans are cut off from the Arctic by submerged ridges, the cold bottom water of the Arctic is unable to creep south into these oceans. On the other hand, all the great oceans lie open to the south, and the cold water from the Antarctic region creeps north along the bottom of the ocean beds, gradually rising in temperature as it advances northward. Consequently, in the Pacific, Atlantic, and Indian Oceans the temperature of the bottom water increases from south to north, and this increase continues beyond the equator. For example, the water at the bottom of the Pacific Ocean near the Aleutian Islands in the north is at a higher temperature than the lower layers of water at the equator in the same ocean.

Figure 54 (dotted lines) shows by a graph the decrease in temperature with depth in a sea inclosed by a submarine ridge. To the depth of the submarine ridge (600 fathoms) the decrease is rapid; beyond that the temperature remains the same right to the bottom of the sea. This is the case in the Mediterranean, the Red Sea, the Caribbean Sea, and several other seas shut off from the ocean by a submarine ridge. The decrease of temperature with depth may be modified greatly in land-locked seas, such as the Gulf of St. Lawrence. In this body of water a layer at a depth of from fifty to seventy fathoms remains at about 32°F. throughout the year. The surface water above this reaches a temperature during

the summer of about 55°F. Below the cold layer, at a depth of from 100 to 250 fathoms, the water is warmer and denser. In fact, it has the same temperature and density as at corresponding depths in the open Atlantic.

79. Sea ice.—Sea water freezes at about 29°F., not at 32°F., the freezing-point of fresh water. The ice formed contains no salt, though it usually incloses small pockets of unfrozen brine. As ice is a very poor conductor, the layer that forms on the Arctic Ocean during a winter is not more than six to nine feet thick, despite the intense cold.

80. Salt in the sea.—If one hundred pounds of sea water is evaporated, there is a residue of about three and a half pounds of salt. This residue, which is known as sea-salt, is composed of a number of substances mixed together. In many parts of the world common salt is obtained by evaporating sea water. If a dozen bottles of water of equal size were collected from various parts of the oceans, and their contents evaporated, the amounts of residue would vary, but the proportions of the components in the residue would be identical.

The salinity of the oceans is greater in some parts than in others. In the doldrums, where there is heavy rainfall, only thirty-five pounds of salt are contained in every thousand pounds of water. In the trade-wind belt, where the drying winds cause great evaporation and where there is little rain, there are thirty-eight pounds of salt in every thousand pounds of water. In the Red Sea, surrounded by a hot desert, there is no less than forty-three pounds. In seas that receive the drainage from great areas, the salinity may be very low.

81. Colour and transparency.—Whenever sea water is free from sediment or organisms, it has a beautiful blue tinge. When it contains small quantities of very fine sediment or organisms, it usually appears green, though

these minute plants and animals in certain cases may give it a brown, red, or olive-green colour. At night certain small organisms cause phosphorescence, especially if they are disturbed. It is not uncommon, on the Atlantic coast of Canada, for the wake of a ship to appear like a stream of light on account of this phosphorescence.

As plants require light, it is of interest to learn to what depth the rays of the sun penetrate the sea water. While very little light reaches beyond a hundred fathoms, quite recently it has been proved that enough light penetrates to 1,000 fathoms to affect a photographic plate exposed for two hours, but that no light is detected at 1,700 fathoms. Accordingly, at the bottom of the ocean at great depths there is the most intense darkness, and plant life is entirely lacking.

Nowhere on the earth's surface are there such uniform conditions as exist at the bottom of the deep ocean. The ocean floor is so nearly level that for hundreds of miles in every direction not even a slight elevation breaks the monotony. The colour of the clay is everywhere dull red. The temperature does not vary by one-tenth of a degree during the whole year. There is no perceptible motion of the water. The deepest darkness prevails at all periods of the day and night and at all seasons. Yet even here there are living creatures—deep-sea fish adapted for life under these strange conditions. These fantastic creatures, accustomed as they are to enormous pressure, never come of their own accord into the upper levels of the water. In fact, to do so would be to court death, as their bodies would be distended and broken if the pressure were to be materially lessened or removed.

QUESTIONS

1. Why is the salinity of the Red Sea greater than that of the Gulf of St. Lawrence?

2. Is the salinity greater in the eastern or in the western part of the Mediterranean Sea? Why?

3. Give a reason for the fact that the eastern part of the Baltic Sea is merely brackish.

4. Why are sounding bottles made of metal of great thickness?

5. Is an iceberg composed of fresh or of salt water? Why?

6. What is probably the food eaten by fishes and other marine animals that live at the bottom of the deepest parts of the ocean?

7. A globular vessel made of thin metal is filled with air. It has a sinker attached and is sunk to the bottom at a deep part of the ocean. Describe what would probably happen to the vessel and to the air.

8. A sound is produced at the surface of the ocean, and the echo from the bottom is heard ten and a half seconds afterwards. How deep is the ocean at the point of reflection? (Velocity of sound in sea-water is 1,732 feet per second.)

CHAPTER IX

WAVES, CURRENTS, AND TIDES

Preliminary Experimental Work

(*1*) *To study the circulation of hot and cold water.*—

Fill a small bottle with warm coloured water, and, covering the mouth tightly with a finger, set it on the bottom of a large vessel full of cold water, and then remove the finger from the mouth. Which way does the coloured water flow? Now fill the small bottle with cold coloured water and the large vessel with warm water, and repeat the experiment, placing the small bottle on its side just below the surface of the water in the vessel. Which way does the water now flow? Or, half fill a broad, shallow beaker with water. When the water becomes motionless, drop one small lump of potassium permanganate into the middle of the beaker, and one toward the margin. Immediately begin to heat the beaker with a small flame directly under the lump at the centre. Observe the currents of water as indicated by the movement of the potassium permanganate. In what direction does the water move (*a*) immediately above the flame, (*b*) at the bottom near the margin, (*c*) near the surface?

(*2*) *To study the effects of wind on the circulation of water.*—

For this experiment a large pan, two or three inches deep, is required. Almost fill the pan with water, and sprinkle fine saw-dust evenly over the surface. By means of a hand bellows blow steadily along the surface of the water. Watch carefully the motion of the saw-

dust. In what direction does the water move? At which side of the vessel does the water tend to heap up? Whence does the water come to take the place of the water moved forward by the wind? As the surface water moves before the wind, in what direction does the water near the bottom probably move? If the surface water were much warmer than the deeper water, which side of the vessel would contain the warmer water at the surface after the circulation had become established? Place a strip of galvanized iron on edge in the water, and bend it into a form to imitate the east coast of South America. Blow along the water toward the angle corresponding to the eastern projection of South America, and observe the circulation. Bend the strip to imitate the coast of the Gulf of Mexico; place a stone in the water to take the place of Cuba; then blow along the water in such a direction that the air currents will represent the trade-winds, and study the circulation.

(3) *To illustrate the motion of waves.*—

Fill a long, narrow trough with water, and place a cork upon the water at about the middle of the trough. With a paddle give the water at one end a sudden push toward the other end of the trough. Describe the movements of (*a*) the wave, (*b*) the cork.

Ocean Currents

82. Detection of currents in the ocean.—The water of the ocean is never absolutely at rest. Its important movements are of two kinds—waves and currents. While ordinary waves are familiar to anybody who has seen a body of water, currents are more difficult to detect. Yet there are many kinds of evidence to prove that there are currents in the ocean. For example, a ship, steaming in a fixed direction at a known speed for a measured time,

may find that it has been carried from its course and so has not reached the position that it should occupy according to its reckoning. As allowance can be made for any drifting caused by the wind, the divergence must be due to ocean currents. Derelicts have been observed intermittently on an ocean for months, and each time they have occupied a new position. Their movement cannot be wholly explained by the effect of the wind, hence it must be chiefly due to currents. Again, many objects, such as sealed bottles with messages and requests, have been dropped into the ocean, and, after varying periods, have been washed up on distant shores. Recently a buoy broke from its moorings in the St. Lawrence River; it was afterwards picked up off the Scilly Islands at the other side of the Atlantic Ocean. The drift of icebergs is almost entirely due to ocean currents or to tidal streams. When icebergs enter the Strait of Belle Isle, for instance, they move back and forth with the flow and the ebb of the tide. So small is the part of an iceberg projecting above the surface of the sea, as compared with the part immersed, that the wind can have little influence in determining the movement of the berg. Ships in the far north are frequently frozen in the field of ice, and in this condition may drift for thousands of miles. The fact that trees which grow only in Siberia had been frequently found to the east of Greenland led Nansen, the great Arctic explorer, to believe that a current flowed across the Arctic Ocean from Siberia to Greenland. Surmising that it might flow past the north pole, he determined to allow his ship to freeze in the ice north of Siberia, in the hope that he would reach the pole by drifting. His plan was almost successful, as his ship drifted to a position nearer the pole than had been reached by any explorer before him. All the foregoing indications of ocean currents have been of great service in the past.

Modern instruments now make more exact methods of detecting currents available. At the present time it is possible, even in mid-ocean, not only to detect a current at any depth, but also to measure its velocity and to determine its direction.

Recently H. N. Dickson, of Oxford University, added much to our knowledge of ocean currents, by examining the salinity and temperature of the North Atlantic Ocean. The water of the northern section of this part of the ocean is colder and fresher than that of the southern section. By studying monthly maps of salinity and temperature, which were prepared from data collected by sea captains, Dickson found that great tongues of fresh, cold, Arctic water extended into the warmer, more saline waters of the south, and vice versa. He concluded that these tongues of water were carried beyond their normal region by currents. Consequently, he was able to trace the courses of the currents of the North Atlantic more accurately than they had ever been traced before. W. Bell Dawson, Superintendent of the Tidal and Current Survey of Canada, also used this method with success in charting the currents of the Gulf of St. Lawrence.

83. Kinds of currents.—The currents in the ocean are of two types. A *drift* current is a broad, thin sheet of water that moves forward slowly, its velocity being not more than fifteen or twenty miles a day. Its boundaries are ill defined. A *stream* current is much narrower and deeper, often extending to a depth of a thousand feet or more. Its velocity is much greater than that of a drift, reaching eighty or even one hundred miles a day. In some cases a velocity of five miles an hour is attained—a speed equal to that of a swiftly flowing river. The boundaries of a stream are better defined than those of a drift; in fact, sometimes they are so clean-cut that it is possible for a ship to be half in a stream current and half

out of it. The boundary between the water of the stream and the water beyond may be detected by differences of colour and temperature. Stream currents, such as the

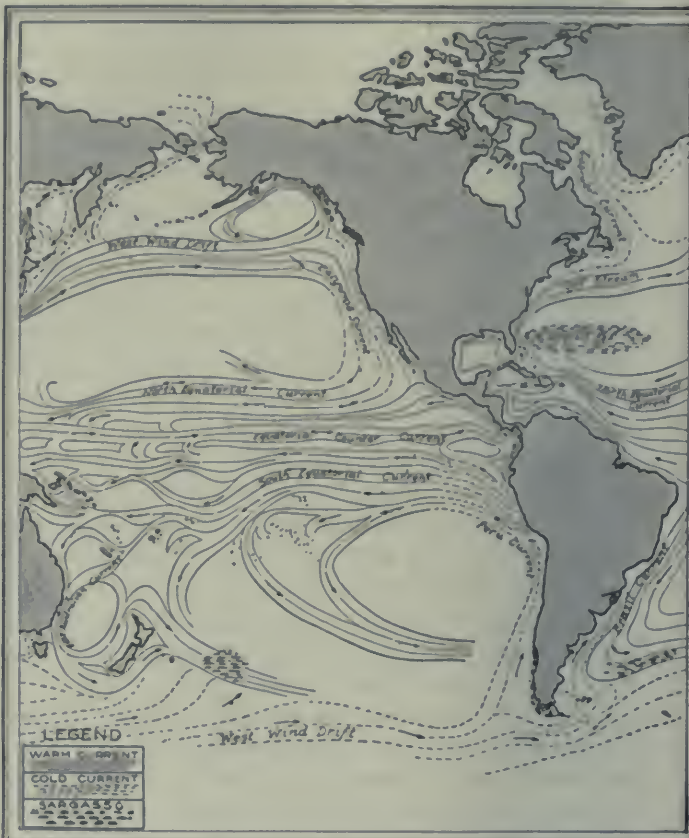
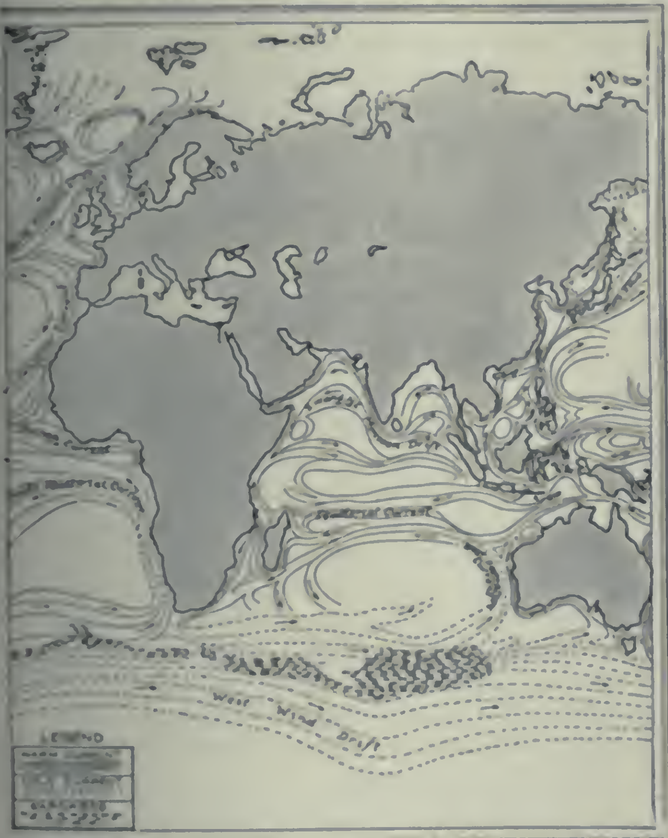


Fig. 55.—Chief currents

Gulf Stream, may properly be called "rivers in the ocean."

84. The currents of the oceans.—Figure 55 represents the main surface circulation of the oceans and shows the

names of the chief currents. On each side of the equator a broad, shallow drift flows from east to west across the Atlantic Ocean, with a velocity of from fifteen to twenty-



five miles a day. Between these two currents is a narrow, ill-defined counter-current, flowing in the opposite direction. The *South Equatorial Drift* is split on the projecting part of South America. The southern and

smaller branch flows down along the coast of Brazil. The northern and major portion skirts the north coast of South America and enters the Gulf of Mexico. Part of the *North Equatorial Drift* unites with the northern branch of the South Equatorial Drift before it enters the Gulf of Mexico. This influx of water tends to raise the level of the Gulf of Mexico, so that a head of water is formed which forces out of the Strait of Florida the most remarkable and best known stream current in the world —the famous *Gulf Stream*. As the Gulf Stream leaves the Strait, it is fifty miles wide and about two thousand feet deep—a vast river of warm water sweeping onward with a velocity of almost five miles an hour. The temperature of its surface water is high, being over 80°F. After leaving the Strait it is joined by the other branch of the North Equatorial Drift, and moves north-eastward at an increasingly great distance from the coasts of the United States and Nova Scotia. It cannot be detected beyond the region just south-east of Newfoundland.

A drift current, called the *West Wind Drift*, moves across the Atlantic Ocean toward Europe. This divides into a northern and a southern branch. The former, called the *European Current*, further subdivides into three main branches. One of these skirts the coast of Norway; another the coast of Iceland; the third moves up Davis Strait close to the coast of Greenland. The southern branch skirts the west coast of Africa and unites with the North Equatorial Drift.

The North Equatorial Drift, the Gulf Stream, the West Wind Drift, and the European Current produce a great whirl, or eddy, in the North Atlantic Ocean. At the centre of this whirl is an area of still water called the *Sargasso Sea*. This sea contains great quantities of floating sea-weed, which is sometimes so matted that it looks as though one could walk upon its surface.

Since in the region of the Roaring Forties (Sec. 51), a West Wind Drift is well developed, there is a South Atlantic whirl similar in most respects to that in the North Atlantic. The current in the South Atlantic, however, moves in a direction opposite to that of the hands of a clock, or counter-clockwise, while in the North Atlantic it moves clockwise.

Besides these two Atlantic whirls there are currents that move from the Arctic and Antarctic regions toward the equator. One of these, the *Labrador Current*, flows along the west side of Davis Strait, moves down the coast of Labrador, and then follows the east coast of Newfoundland. It then hugs the coast of the United States as far as Cape Hatteras, but there disappears, probably passing under the Gulf Stream. During the winter this current terminates the northerly flow of the Gulf Stream, and thus forms a cold wall between the warm waters of the Gulf Stream and the waters of the West Wind Drift.

In the Pacific Ocean (Fig. 55) there are two whirls of water comparable to those of the North and the South Atlantic Ocean. In the North Pacific the *Kuro Siwo*, or *Japan Current*, corresponds to the Gulf Stream in the Atlantic, and a West Wind Drift also moves across the Pacific to the coast of British Columbia.

In the Indian Ocean (Fig. 55) south of the equator, there is a whirl similar to those in the South Atlantic and the South Pacific. North of the equator is a whirl which moves for half the year in one direction and for the other half in the opposite direction, the change of direction corresponding with the change in the direction of the monsoons.

The current just north of Antarctica, in 60° south latitude, which moves from west to east around the world, appears to be the greatest of all drift currents. Under the influence of the steady west winds, it moves

forward with a velocity which sometimes reaches more than two miles an hour. No other drift moves at so great a speed.

Besides the great ocean currents, there are currents through straits that separate the ocean from adjoining seas. As the Mediterranean Sea and the Red Sea are in regions of little rain and great heat (Fig. 15), the water lost by evaporation is much greater than that supplied by rain and rivers. Accordingly, there are strong surface currents into the Mediterranean Sea through the Strait of Gibraltar and the Dardanelles, and into the Red Sea through the Strait of Bab-el-Mandeb. On account of the small rainfall and the great evaporation over the Mediterranean and Red Seas, the water in them is much saltier than that of the oceans. Since the density of salt water increases with its salinity, at considerable depths the pressure of the more saline water of the seas is greater than the pressure of the less saline water of the ocean at the same level. Consequently, at a depth of several hundred fathoms there is a current through each of these straits from the sea to the ocean. Thus there is an in-coming surface current through these straits, and an out-going current at a deeper level.

Besides the currents described above, there are both vertical and horizontal movements of the water so slow that they are difficult to detect. For example, there is the slow creep northward of the cold Antarctic waters along the bottoms of the three great oceans.

85. Causes of ocean currents.—If a piece of ice is placed at one end of a long vessel full of water and the water at the other end of the vessel is kept warm, a regular circulation of the water results. The warm surface water flows toward the ice, the cold water near the ice sinks, a cold current moves along the bottom from the cold to the warm area, and then, becoming warm, rises,

forcing more warm water across toward the ice. Similar conditions obtain on the oceans, and, as a result, the cold water from the south polar regions creeps along the bottom toward the equator.

Wherever there is a difference in level between two adjacent areas of the ocean, there is always a surface flow from the region of higher level to the region of lower level. Excessive rainfall, or a large volume of water poured into the ocean from rivers, causes an elevation of the water level in the region affected, while excessive evaporation produces a depression of the level of the water. Wherever there is a difference in density between two adjacent areas of the ocean, there is always a movement from the area of greater density to the area of less density. Increased salinity or decreased temperature causes an increase of density.

The effect of these agents, however, in producing currents, is slight when compared with the great part played by the winds. When winds blow over the surface of the ocean, the friction between the air and the water causes the surface layer of water to move in the direction of the wind. This movement of the upper layer is gradually transmitted by friction to the water below to a depth of several hundred feet. The prevailing winds determine, to a great extent, the direction of the great surface currents of the ocean. The equatorial currents in the three oceans are caused by the trade-winds. The West Wind Drifts in the temperate zone are all driven eastward by the prevailing westerlies. An English geographer constructed an accurate model of the Atlantic Ocean and placed water on it to the proper depth. He then caused air currents to blow over the water in the direction of the trade-winds and the westerlies. The currents thus produced imitated so closely those of the Atlantic Ocean, that no doubt remained as to the close relation

between the prevailing winds and the ocean currents.

While winds originate and drive forward the surface currents, two other factors help to determine their direction. The first is the shape of the coasts against which the currents strike; as, for instance, the effect of the coast of Brazil upon the South Equatorial Drift. The second is the influence of the earth's rotation. The effect of the latter is the same on water as on air (Sec. 46), deflecting all currents in the northern hemisphere to the right of their course and all in the southern hemisphere to the left of their course. Thus the Gulf Stream is gradually deflected from the American coast, while the Labrador Current is thrown close to the coast throughout its course, in each case the deflection being to the right.

86. The effects of ocean currents.—Ocean currents have had a marked effect on commerce. Since the direction of the surface currents of the ocean and the prevailing winds are in most cases the same, sailing vessels naturally shape their courses so as to secure the double advantage of favourable wind and current. Some of the stream currents, such as the Gulf Stream, which flow rapidly and are not directly determined by the winds, have also had a marked influence on the courses of ships. Ocean currents also have some effect in modifying climate, but this is not so considerable as was once thought. Even if there were no currents in the North Atlantic, the westerlies blowing from the Atlantic during the winter would greatly moderate the climate of western Europe. Again, Labrador is bleak, not so much because of the proximity of the Labrador Current, as because its prevailing winds blow from the cold interior of northern Canada.

Waves

87. Nature of waves.—The waves of the surface of a

body of water are the best known of all its movements. When a stone is dropped into water, successive waves travel outward in ever enlarging circles. A wind, blowing over the surface of a body of water, soon causes waves to form, and the greater the velocity of the wind, the higher and longer are the waves. Water waves consist of a succession of crests and hollows (Fig. 56). The distance

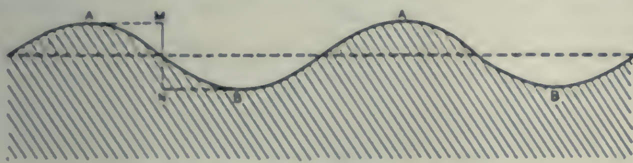


Fig. 56.—Section through water waves

from crest to crest (*A* to *A*) or from hollow to hollow (*B* to *B*) is called the *wave-length*, and the vertical distance from the top of the crest to the bottom of the hollow (*M* to *N*) is called the *amplitude*, or *height* of the wave. While the waves of a body of water in which there is no

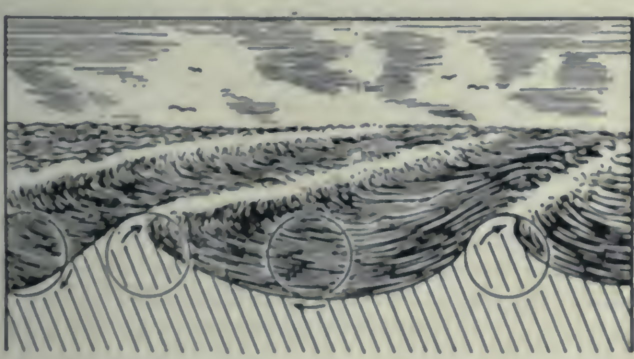


Fig. 57.—Section through water-waves. The circles indicate the paths taken by the particles of water, the arrows the directions

current move forward, a piece of wood floating on its surface has scarcely any forward movement, but merely rises on the crests and sinks into the hollows of successive

waves. The water particles composing the wave rise and fall like the object floating on the surface, so that there is no actual forward movement of the water itself, which merely rises and sinks in the same place. Each of the particles of water rises with the advance of the crest and falls with the advance of the hollow. The particles do not rise and fall in a vertical line, but move in a vertical circle as represented in Figure 57. Vertically below the crest they move in the direction of the advance of the wave, and vertically below the hollow they move in the opposite direction, as indicated by the arrows. The size of the circle in which the water particles move is greatest at the surface and rapidly decreases with the depth. In a wave 500 ft. long and 30 ft. high, a particle of water at the surface moves through a circle whose diameter is 30 ft., while a particle at a depth of 500 ft. moves through a circle whose diameter is not more than 1 inch. The particle, at a depth of 500 ft., would not make more than five revolutions in a minute. Accordingly, the force of the wave movement decreases rapidly with increasing depth. In shallow bodies of water such as Lake Erie, the waves may stir up the bottom so as to make the whole lake turbid; but in the deep water of the ocean the bottom is undisturbed by even the most violent storms.

88. The phenomena of waves.—The height and the length of a wave depend on several factors. If the water is deep, the size of the wave depends on the velocity of the wind, on the length of time it has been blowing, and on the length of the uninterrupted sweep of the wave itself, or its *reach*. On the ocean, where the conditions for the formation of large waves are most favourable, they occasionally reach a height of over 40 feet and a length of 1,000 feet or more. On Lake Superior the

largest waves are from 20 to 25 ft. high and from 275 to 325 ft. long.

The velocity of waves in deep water depends on their height and length. The long, high wave moves fastest. In shallow water the friction of the bottom checks the movement of the lower part of the wave. As the wave approaches the shore, the under half is checked more and more, while the upper part is unimpeded; until at last the upper part curls over and breaks upon the beach. The heaviest and most powerful breakers in the world are those on the Guinea Coast of Africa, where there is a constant swell rolling in from the South Atlantic.

The friction of the bottom also has the effect of turning waves, whatever their initial direction, parallel with the shore. When a wave approaches the shore obliquely, the end of the wave closer to the shore feels the retarding effect of the friction of the bottom first. Therefore the forward movement of that end of the wave slackens, while the other end moves on with speed unchanged. This continues until both ends are in water of equal depth, that is, parallel with the shore.

89. The work done by waves.—Waves bring all parts of the water from considerable depths to the surface, where it becomes impregnated with oxygen from the air. They are also important agents in sculpturing rocky coast-lines into many fantastic shapes (Sec. 136).

The force of the waves is so tremendous that engineers who construct piers and breakwaters in harbours find it very difficult to cope with their destructive power. At Peterhead, Scotland, where the reach of the waves is three hundred miles, blocks of concrete weighing forty tons and placed forty feet below low water have been displaced by the waves. During the construction of Plymouth breakwater blocks of stone, weighing from seven to nine tons, were carried clear over the breakwater

in a violent storm. At Bishop Rock lighthouse the waves tossed an iron column, weighing over three tons, to a height of twenty feet and lodged it on the top of a rock.

The innumerable waves on all great bodies of water exert so great a force in the aggregate, that the combined power of Niagara Falls and all the other cataracts of the world is insignificant compared with theirs. Yet up to the present man has failed to harness this mighty power for his use.

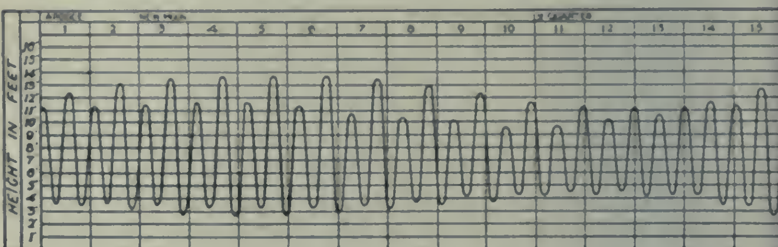


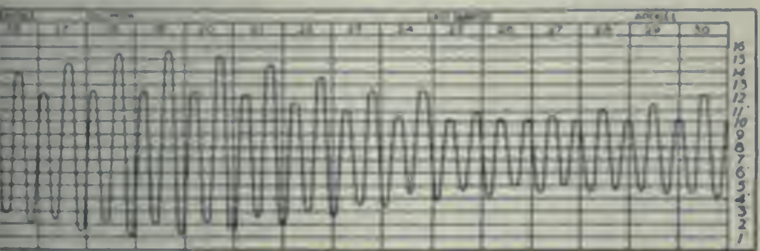
Fig. 58.—Graph of the tides at Father Point.

Tides

90. High and low tides.—The level of the water along the shores of the Great Lakes changes very little from hour to hour or from day to day. The level of the water along the sea-coast, however, rises and falls periodically. The slow but steady rise of the water continues for almost six hours; then, after a short pause, the water begins to recede. After slowly receding for almost six hours, it again pauses for a short time. Then the whole process is repeated. The high water is called *high tide*, and the low water is called *low tide.* The average time between two successive high tides or between two successive low tides is twelve hours and twenty-five minutes, but there may be a wide variation from this average. On an exposed coast, as in the Gulf of St. Lawrence, the difference

in height between high and low tide is not more than four or five feet, while in narrow bays and the mouths of rivers the tide may rise at times to a height of forty or fifty feet.

91. Spring and neap tides. — Figure 58 is a graph of the tides at Father Point on the Lower St. Lawrence for the month of November. Notice that the high tides steadily become higher, and the low tides steadily become lower, until about November 4th or 5th, immediately following the new moon. Then the



Quebec, for the month of November, 1918

height of the high tide begins to decrease, and the height of the low tide begins to increase. This continues until about November 11th or 12th, when the first quarter of the moon is reached. The range of the tides then begins to increase once more, reaching a maximum at about the full moon on November 18th or 19th. Then the range again diminishes until the third quarter of the moon. This periodic fluctuation correlated with the phases of the moon is observed to occur very generally. The tides with maximum range, which occur near the time of new or full moon, are called *spring tides;* those with minimum range, which occur at the first and third quarters of the moon, are called *neap tides.* The tides of many parts of the world have well-marked springs and neaps like those just described. As the tides of Western

Europe usually show this characteristic prominently, the idea has become prevalent that this is the most characteristic phenomenon of tides in all parts of the world. But such is not the case. For example, if the tides of St. John, N.B., are examined, it will be found that their maximum range does not occur at new and full moon unless the moon is in perigee. This characteristic is also very marked in the tides of Hudson Strait.

92. Tides and estuaries.—The tidal movement is really an advancing wave ; and the explanations regarding wave motion apply also to it. The tide advances as a very long wave. While the crest is approaching a point, the tide is rising. After the crest has passed, the tide falls until the middle of the hollow of the tidal wave is reached. On the open sea it is probable that the height of the tidal wave is not more than two feet, and on open coasts, as at St. Paul's Island in Cabot Strait, it is only two or three feet in height. When the tidal wave enters a narrowing bay or the wide mouth of a river, its height is much greater. As it advances into an ever-narrowing channel, it rises higher and higher, and, as the depth of water decreases, it advances more and more slowly. After a time, however, it exhausts itself, and in the upper reaches of a tidal river the range of the tide steadily diminishes. These facts can be observed in the rivers emptying into the Gulf of St. Lawrence, and especially in the St. Lawrence estuary. The rise during *flood tide* is accompanied by a strong current up stream, and the fall during *ebb tide* is accompanied by a current down stream. These currents keep the bed of the river well scoured and prevent sand-bars and deltas from forming. Under certain conditions the advancing tide assumes the form of a wave with an almost vertical front. Such a tide is called a *bore.*

93. Tides in the Bay of Fundy.—In the Bay of Fundy

(Fig. 59) occur some of the highest tides in the world. These are in Cobequid Bay, where the greatest recorded range of a single tide is slightly over fifty-three feet. At the head of Chignecto Channel, in the northern branch of the Bay of Fundy, occurs one of the most noted bores in the world. It runs up the Petitcodiac River for twenty-one miles and can be readily observed at Moncton.

Fig. 59.—The Bay of Fundy, showing the position of the bore and of the highest tides in the world

94. Importance of tides.—If there were no tides, some of the greatest seaports in the world would never have existed. Britain especially would suffer, as some of her finest and busiest harbours are situated on tidal estuaries. The tidal currents keep the channels of the estuaries

scoured clean, and twice a day fill them with water, so that the largest ocean steamers can penetrate far up their channels, which, without tides, would contain little water. Liverpool, Bristol, and certain other great ports are accessible to ocean-going vessels only because of the tides.

Practical Exercises

To study from a map of the ocean currents their courses, causes, and effects.—Figure 55 marks the ocean currents of the world. What is the direction of the main currents in the Atlantic Ocean on both sides of the equator? What is the direction of the winds in this region (Fig. 29)? What is the main direction of the currents between 40° and 60° in the North and the South Atlantic? What is the direction of the winds in these regions? Consult Section 83 and find whether these currents are stream or drift currents. What are the names of these currents? If there are steady currents from east to west across the Atlantic Ocean on each side of the equator, what effect must they have on the level of the water on the east and west sides of the Atlantic between the tropics? What effect must the West Wind Drifts have on the level of the water in the North and South Atlantic between 40° and 60°? In what direction must the currents flow on the west side of the Atlantic Ocean between the region of the Equatorials and the West Wind Drifts? What difference of level should the Equatorials and the West Wind Drifts tend to produce on the east side of the Atlantic? In what direction do the currents flow that move between the West Wind Drifts and the Equatorial Drifts on the east side of the Atlantic? What effect has the projecting part of South America on the South Equatorial Drift? Trace the course of the branches of the West Wind Drift in the North Atlantic. What is

the direction of the current near the equator between the North and South Equatorial Drifts? By an examination of a map of the winds (Fig. 29), note the relation of this current to the doldrums. Refer to your conclusions as to the relative levels of the east and west sides of the Atlantic in this region, and then give a probable explanation of this counter-current. Are currents flowing away from the equator warmer or colder than the parts of the ocean to which they flow? Are currents flowing toward the equator warming or cooling currents? Why are the isotherms of 70° (Fig. 15) farther apart on the west than on the east side of the Atlantic Ocean? Why do the isotherms of 40° and 50° in the North Atlantic run north-east from America to Europe? Does a warm or a cold current directly affect the climate of the adjacent land? If a prevailing wind blows from a warm current to adjacent land, what effect will it have on the climate of the land?

Compare the currents in the Pacific Ocean with those in the Atlantic. Are there equatorial currents and equatorial counter-currents in the Pacific? Are there North and South West Wind Drifts? What current in the Pacific Ocean corresponds to the Gulf Stream? To the Canaries Current? To the Norwegian Current? Is there a current corresponding to the Labrador Current? Do the currents in the North and South Pacific whirls move clockwise and counter-clockwise respectively?

Compare the currents in the Indian Ocean south of the equator with those in corresponding parts of the Atlantic and Pacific Oceans. Study the winds north of the equator in the Indian Ocean (Fig. 30), and then explain why the currents in this region take one direction during the summer and an opposite direction during the winter, as indicated on the map.

QUESTIONS

1. Branches of trees that grow only in Siberia are occasionally washed ashore on the west coast of Greenland or on Iceland. What can be inferred from this as to the currents of the Arctic Ocean?

2. If the level of the water in a sea is 40 cm. lower than in the ocean, in which direction will the surface currents flow? If the density of the water in the Mediterranean Sea is 1.029 g. per c.c., and in the Atlantic Ocean just outside the Strait of Gibraltar 1.026 g. per c.c., compare the pressure due to the weight of the water at a depth of 200 m. in the Mediterranean Sea with the pressure at the same level in the Atlantic Ocean. In which direction will the water move at this depth?

3. Why are deltas formed at the mouths of most of the rivers of Europe emptying into the Mediterranean, Black, and Caspian Seas, while deltas are not usually formed at the mouths of the rivers of Europe emptying into the Atlantic Ocean?

4. Which will produce the larger waves on Lake Ontario, a north or an east wind of the same velocity (Sec. 88)? Give a reason.

5. When the wind is from the south, will the waves be higher on the north or the south side of Lake Erie? Give a reason.

6. If the water in a harbour is deep, is it an advantage or a disadvantage to have tides?

CHAPTER X

ROCKS

Preliminary Experimental Work

(*1*) *To study the properties of the rock-forming minerals.*—

Materials—For each pupil specimens of quartz, feldspar, mica, calcite, and hornblende (one or two varieties of each).

Describe the colours of the several varieties of quartz. Describe the fracture, noting whether the surface is jagged, or smooth and curved. Will quartz scratch glass? Describe the lustre, that is, whether it appears glassy, or resinous, or metallic. Try to melt a piece of quartz in a hot flame (use a blow-pipe, if possible).

Examine each of the other minerals in a similar way.

(*2*) *To study the properties of aqueous rocks.*—

Materials—For each pupil specimens of several varieties of sandstone, of limestone, and of shale; a piece of conglomerate; hydrochloric acid.

Describe the colours of the samples of sandstone. Observe the layering. With the aid of a lens examine a piece of sandstone and describe its surface. Rub it between the thumb and the finger and describe the "feel." Try to dissolve it in hydrochloric acid. Pulverize a small piece by pounding it with a hammer.

Examine each of the other varieties of aqueous rock in a similar way.

(*3*) *To study the properties of igneous rocks.*—

Materials—Samples of at least two varieties of trap rock, a sample of granite, and one of syenite.

Examine a piece of granite with the naked eye and also with the aid of a lens; describe its colours, and name the minerals that you recognize in it. Describe the arrangement of the minerals. What mineral is in the greatest proportion, and what one is in the smallest proportion?

Examine and describe syenite in a similar way.

What are the colours of the several varieties of trap rock? Compare the structure of trap rock with that of granite and of syenite.

(4) *To study the properties of metamorphic rocks.*—

Materials—For every pupil, specimens of gneiss, schist, slate, marble; hydrochloric acid.

Examine a sample of gneiss with the naked eye and with the aid of a lens. What minerals does it contain? Describe the arrangement of these minerals. What igneous rock does it most nearly resemble? How does it differ from this igneous rock?

Examine a specimen of slate. Note the size of the particles of which it is composed. Can they be distinguished? Describe its "feel." Test its hardness by scratching it with a knife, and by determining whether it will scratch glass. Has powdered slate an odour when wet? How does acid affect it? Which of the sedimentary rocks does slate most nearly resemble? State the points of resemblance and of difference.

Examine, test, and describe each of the other kinds of metamorphic rocks in a similar way.

(5) *To demonstrate the sorting power of water.*—

Mix together pulverized clay, very fine sand, coarse sand, and small pebbles. Place the mixture in a tall, clear glass bottle, which is nearly full of water. Shake vigorously. Allow the mixture to settle for half an hour.

What materials have settled during this time? What materials settled first? What materials did not settle

within half an hour? Allow the bottle to stand for a day, and examine the contents again. What material did not settle?

If the water had been running with a moderate current, infer the relative location of the several materials after they had settled from the water. Test the correctness of your conclusion by examining the order in which these materials are deposited by a local stream or ditch, or by the water in a furrow on a hillside.

(6) *To demonstrate the growth of crystals.* —

(*a*) Make a strong solution of alum, by stirring powdered alum in a beaker of hot water until no more will dissolve. Hang a piece of string in the beaker and let it stand for a day or two. Remove the string from the beaker and describe what you see. (*b*) Make a strong solution of blue vitriol by adding powdered vitriol to boiling water until no more will dissolve. Spread a few drops of the solution on the surface of a glass plate and observe what takes place during the process of cooling.

THE LITHOSPHERE

95. The meaning of lithosphere. — In preceding chapters references have frequently been made to the solid crust of the earth, to which is given the name *lithosphere.* The name means a sphere of stone, and signifies that the portion of the earth surrounding the vast, unknown interior to which we give the name *nucleus*, is composed essentially of rock. To those whose acquaintance with the earth's crust is limited to the loamy areas of southern Ontario this description may seem inapt, but it is really quite appropriate. Borings sunk deep into the earth's crust show that it is composed of comparatively thin layers of soil spread over thick layers of solid rock. Moreover, the sands and clays that are

the essential components of soils, are, as we shall learn in succeeding chapters, the grist obtained by the grinding of rocks of every kind, from the hardest granites to the softest shales. For this reason geologists class as rock any form of matter that constitutes a considerable portion of the earth's crust. Banks of clay and sand, ridges of gravel, and beds of peat and coal are, therefore, rocks within this meaning of the term, for they all form part of the earth's crust.

96. The earth is probably a solid sphere.—The term *crust* is a remnant of the belief that the interior of the earth is a mass of intensely hot molten matter, upon which floats a solid crust, in much the same way as the thin film that forms on the surface of molten lead floats upon it. Although this belief has still some adherents, the theory that the core, or nucleus, of the earth is solid is now generally accepted. The following are a few of the more important arguments that are advanced in support of the theory that the earth is a solid body:

(1) Solid rock does not float upon the surface of molten rock in the same way that a layer of ice floats on water, but sinks in molten rock; hence the earth's crust must be supported on a solid core.

(2) The velocity with which earthquake waves pass completely through the earth along a diameter is so great that only a core at least as solid as steel can account for the speed of transmission.

(3) The melting-point of any substance which expands when melting, rises with increase in the pressure to which the substance is subjected. The pressure of the outer layers of the lithosphere upon the nucleus is so great that fusion of the matter subjected to this pressure is impossible.

(4) The velocity with which the earth rotates has decreased very little throughout the ages. This fact

cannot be explained except by the absence of frictional resistance to the movement of the rotating earth. A liquid interior would offer considerable resistance to this movement; hence it is necessary to assume that the interior of the earth is solid.

Lord Kelvin, who developed this argument, used by way of illustration two eggs, one hard-boiled and the other unboiled. If both eggs are set whirling simultaneously at the same rate, the hard-boiled egg will continue to rotate much longer than the unboiled one.

97. The general relations between land and water.—We must regard the nucleus and the lithosphere of the earth as an essentially solid mass, with surface elevations constituting the continental areas and surface depressions occupied by the oceans. The highest altitudes of the land areas are approximately six miles above sea-level, and the lowest depths of the ocean reach an equal distance below sea-level. There is an intimate relation between land and water, as a constant interchange of the mineral contents of the sea and of the land is always in progress. By this mutual transfer, existing rock masses are continually being dissolved, to swell the mineral content of the oceans; and at the same time extensive land areas are constantly being built up from materials coming from the sea.

The Rocks of the Lithosphere

98. The general structure of rocks.—Occasionally rocks are found in masses that show no tendency to split in any definite way. Such rocks are said to be *massive*. More usually rocks show a *bedded structure* (Fig. 60), the whole mass being made up of a number of distinct layers placed one above another, like planks in a pile. The pile in some cases remains upright, with the layers horizontal, but in others it is tilted at various angles.

In addition to divisions into layers, rocks are frequently traversed by deep cracks called *joints*. These joints are perpendicular to the bedding planes and divide the rocks into almost rectangular blocks. In all rocks irregular fractures that have no systematic arrangement occur. Slipping sometimes takes place along bedding, joint, or fracture planes.

Courtesy of Canada Publishing Co., Toronto
Fig. 60.—Gorge of the Grand River at Elora, Ont.

Such slippings produce *faults* (Fig. 61).

99. The composition of rocks.—Of the ninety or more elements composing the lithosphere, only eight play any extensive part in its composition. Oxygen constitutes almost half and silicon more than a quarter of the whole, and aluminum, iron, calcium, magnesium, sodium, and potassium, in the order named, make up the greater part of the remainder. Occasionally an element is found in a free form, that is, uncombined with other elements. For example, free carbon occurs in the form of coal and diamonds; gold, copper, and silver are found as pure metals, or *native*, as the miner terms it. More commonly the elements are combined to form compounds. A free element or a compound that exists in the earth's crust and enters into the composition of rocks, is called a *mineral*. Examples of minerals are quartz, calcite, gold, etc. Quartz is a compound made up of the two elements, silicon and oxygen. In some instances rocks are wholly made up of this mineral, but rocks formed of quartz crystals mingled with other minerals are of more common

occurrence. Granite rocks are representatives of this form.

100. Kinds of rocks.—We have learned that a rock is composed of a single mineral or of granules of several minerals mixed together in an irregular manner. The

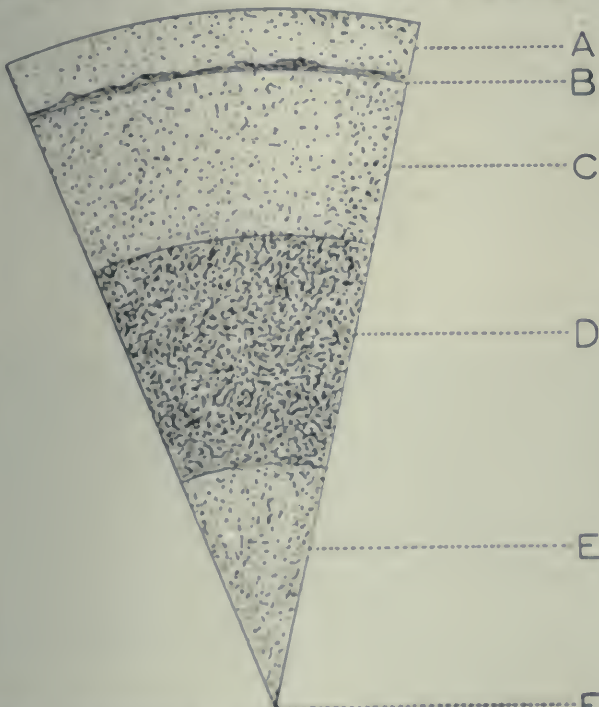


Fig. 61.—One conception of the earth based upon variations in the velocity of transmission of earthquake waves. *A*, Atmosphere. *B*, Rock and soil, as known by borings, etc. *C*, Zone of flowage rocks; earthquake movements take place here. *D*, Zone composed of nickel-iron. *E*, Iron and stone mixture. *F*, Centre; pressure here is 15,000 tons per square inch.

great variety found among rocks is due in part to differences in mineral composition, and in part to differences in the modes of origin of the rocks. A piece of pumice-stone, such as may be purchased at a druggist's, is the

solidified froth of molten rock from a volcano. It is of the same chemical composition as the hard, reddish pebbles which are so common in Ontario, especially along the shores of the Great Lakes. These, however, are fragments of rock that solidified deep within the earth.

All rocks that form any considerable part of the earth's crust are grouped under four main heads, according to their origin. These groups, in turn, are subdivided according to the chemical composition of the rocks forming them. The four main groups are:

(1) Aqueous rocks
(2) Igneous rocks
(3) Metamorphic rocks
(4) Aeolian rocks.

Aqueous Rocks

101. The origin of aqueous rocks.— These rocks have been formed chiefly through the agency of water (Latin—*aqua*, water). Every rain-storm causes pebbles, sand, and clay to be washed from the surface of the higher lands and to be swept by the streamlets and rivers to lower levels, where the decrease in the carrying power of the water causes the deposition of sediment. The stones and coarse pebbles are the first to be dropped; then the sand and coarser particles of clay sink to the bottom; then, finally, the finer clay particles, which are held in suspension for days after the flood waters have passed into the quiet waters of the lakes and seas. The streams also carry down much dissolved limestone. This may be taken from the water by living organisms and used by them to form protective coverings, such as we see on clams and other shell-fish. The chemical energy of the sun causes a certain amount of the dissolved limestone to be precipitated. These sediments and precipitates, along with the shells of certain aquatic organisms, furnish

the materials of *aqueous*, or, as they are also called, *sedimentary rocks*.

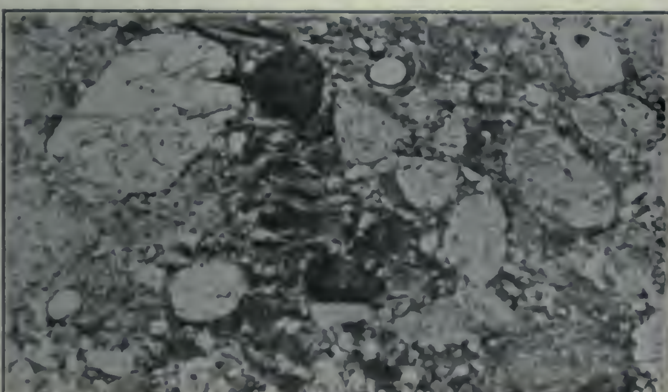
102. The characteristics of aqueous rocks. — As a direct outcome of their mode of origin, aqueous rocks have the following distinctive characteristics:

(1) They are composed of material derived from earlier rocks.

(2) They show the sorting effect of water due to the disposition of the coarser and the finer materials in different places.

(3) They show layering, or stratification. This arises from the difference between the carrying power of streams when in flood and when at low water. Each fluctuation gives rise to a layer, or stratum.

103. Forms of aqueous rocks.—In addition to beds and banks of loose sand, clay, and gravel, there are many



Courtesy of the Geological Survey, Canada
Fig. 62.—Coarse boulder conglomerate, Trethewey mine, Cobalt

solid rocks which have been formed from these loose materials, partly by pressure and partly by a process of cementing. The cement, which consists in some cases of clay, in others of compounds of iron, or of silicon, or of

lime, is distributed throughout the whole mass by water percolating through it, until the accumulation of this cement binds the whole mass into a solid rock. The following are the commonest forms of rocks which originate in this way: *conglomerate*, *sandstone*, *shale*, and *limestone*.

104. Conglomerate.—A conglomerate or, as it is sometimes called, "pudding-stone," is a rock that is formed by the cementing together of coarse materials such as pebbles and stones (Fig. 62). Its appearance is very similar to that of the coarser forms of concrete which are found in the foundations of pavements and in the walls of buildings.

105. Sandstone.—Sandstone is produced by the cementation of sand into a solid rock. Its usual colours are reddish-brown and grayish-white. It is much prized

Fig. 63.—Parliament Buildings, Toronto, Ontario

as building material, and many public buildings, including the Ontario Parliament Buildings, are built of red sandstone (Fig. 63). Sandstone has been quarried at Credit Forks, at Kingston, and at other places in Ontario.

106. Shale.—Clay, solidified by pressure and cementation, forms shale (Fig. 64). Wet shale, when rubbed

with the finger, has a smooth, soft "feel," resembling that of clay. This is an easy way to distinguish shale from sandstone, for the latter retains the rough, gritty "feel" of sand.

Courtesy of the Geological Survey, Canada
Fig. 64 —Stratified shales with underlying Medina sandstone, Jolly Cut, Hamilton

The rocks of the valleys of the Don and the Humber, those of the lower layers of the Niagara gorge, and the dark bituminous rock found near Collingwood, are examples of shales. Shales are of considerable value, as they furnish excellent material for making bricks.

107. Limestone.—Limestone is one of the most abundant of the aqueous rocks and is widely distributed throughout Ontario. The scenic beauty of many localities, such as Elora, Wiarton, Owen Sound, and Niagara Falls, is due to remarkable limestone formations (Fig. 65). It rivals sandstone as a building material, and from it we obtain lime, useful in so many ways. Some varieties of limestone furnish one of the raw materials from which cement is made.

Courtesy of F. J. Capell, Elora
Fig. 65.—Remarkable limestone formation, Elora

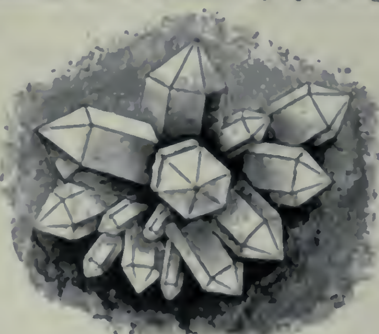
Limestones range in hardness from the soft clay-like marl, which is found in old lake beds, and which consists in large measure of fragments of the shells of aquatic animals, to the firm quarry rocks of Owen Sound, Hagersville, Queenston, and elsewhere. There is considerable variety of colour among limestones. Grayish-white is the prevalent colour of the limestones of western Ontario, but those of the St. Lawrence valley are almost black.

Igneous Rocks

108. Origin and distribution of igneous rocks.—Igneous rocks (Latin—*ignis*, fire) are formed by the solidifying of molten matter. Although the interior of the earth is normally kept in a solid state by the enormous pressure to which it is subjected, frequent rents occur in the overlying strata, which so far relieve the pressure upon the heated interior masses that the latter fuse into a liquid which is called *lava*. Lava is the material from which igneous rocks are derived. Readers who are familiar with the mottled reddish, greenish, and grayish boulders of southern Ontario, and those who have seen

the rock masses of Muskoka or of Hastings, have already made the acquaintance of igneous rocks. They include some of the most ancient rocks, such as those of the Laurentian Highland (now called the Canadian Shield), and also some of the youngest, such as those produced by recent lava discharges from volcanoes. Igneous rocks may be distinguished from aqueous rocks by the absence of stratification. Because of the solid unlayered structure of these rocks they are frequently described as *massive*.

109. The causes of variations in the forms of igneous rocks.—Variations in the forms of igneous rocks arise from two causes. In the first place, the lavas poured forth from the different parts of the earth's crust do not all contain the same minerals, and, consequently, these lavas produce rocks of different mineral compositions. In the second place, the physical properties of the resulting rocks depend upon the conditions under which the lavas cool, in the same way that the product from a thick syrup depends upon whether it is cooled by pouring it upon a block of ice, or by permitting it to cool slowly. When lavas spread out over the surface of the earth and cool quickly, they form either a glassy rock, or one in which the crystalline structure is so fine as to be scarcely distinguishable. Natural glass, or obsidian, is an example of this; and pumice-stone is similar, except that the latter contains numerous cavities formed by bubbles of escaping steam. When lavas are covered by thick layers of the



Courtesy of Department of Mines, Queen's University, Kingston

Fig. 66.—Quartz crystals

earth's crust, the cooling process is so slow that the minerals have time to grow into crystals (Fig. 66). Many igneous rocks are formed under the latter conditions and have crystalline structure, as, for example, granite. A heap of ordinary sand is composed of fragments of crystals, which have been rounded and polished by wave action. This can be seen by examining a pinch of shore sand under a hand lens. In many rocks the crystals can be distinguished by the unaided eye, and it is not unusual to find individual crystals of large size.

110. Granite.—Granite is one of the commonest forms of igneous rocks. The several varieties are all mottled rocks of some shade of gray or red. Stones and boulders of granite are widely scattered over the surface of southern Ontario, and granite rocks are common in the Canadian Shield. Monuments and ornamental stones used in buildings are frequently cut from granite.

A close examination of a piece of granite will show that it is composed of three minerals—quartz, a crystalline mineral with a glassy lustre; feldspar, a pink or brown or whitish mineral that breaks with flat surfaces; and hornblende, which is hard, black, and brittle. Mica may be present in place of hornblende. Mica is a soft, flexible mineral, which, when found in large, transparent pieces, is used for making the windows of stoves.

111. Syenite.—Syenite rock resembles granite very closely in general appearance, but it does not contain quartz. The minerals composing syenite are hornblende or mica and feldspar. The economic uses of syenite are the same as those of granite, and it is found in similar locations.

112. Trap rock.—It is customary to place under this designation all those igneous rocks which are of fine grained texture and which vary in colour from light green to dark green and black. It includes several kinds of

igneous rocks which are difficult for the beginner to distinguish. They are all very dense, hard rocks; and their density and hardness have won for them the name *hard-heads*. When crushed they make excellent road material.

Metamorphic Rocks

113. The origin of metamorphic rocks.—Metamorphic (Greek—*meta*, denoting change, and *morphe*, meaning form) signifies that the rocks of this class are produced by the alteration of other kinds of rock without melting taking place at any stage of the process. Both sedimentary and igneous rocks are subject to metamorphism, as, for instance, when shale changes to slate, or granite to gneiss.

114. The forces causing metamorphism.—The chief forces which cause the metamorphosis of rocks are heat, pressure, movement under pressure, and the action of highly heated water containing dissolved chemicals. These forces are the results of the settling and folding of the earth's crust. It is a matter of common observation that firm rubbing upon a part of the body produces a sensation of heat. When great masses of the earth's crust slide over the layers beneath them, the friction and the pressure generate intense heat. The enormous pressure prevents the melting of the rocks, but the heat and the movement cause an alteration in the structure and arrangement of the rock granules.

115. The forms of metamorphic rocks.—Metamorphic rocks usually retain some resemblance to the rocks from which they were produced. They include slate, gneiss, and marble.

116. Slate.—Slate is derived from shale by metamorphism. It differs from shale in having a more metallic ring when it is struck, and also in fracturing along planes

that do not correspond to the original bedding planes of the shale. The ribbon-like markings that are frequently seen on the surfaces of slates represent the original bedding planes.

117. Marble.—Marble is a metamorphic product of ordinary limestone. The broken surface of a piece of marble shows a uniform crystalline structure, while ordinary unmetamorphosed limestone is usually non-crystalline.

118. Gneiss.—Gneisses are gray, green, or red in colour, and thus many of the varieties resemble granites in this

Courtesy of the Geological Survey, Canada
Fig. 67.—Gneiss, showing banded structure

respect. They also have essentially the same composition as the granites or syenites from which they are derived by metamorphic action. The distinguishing characteristic of gneiss is the arrangement of the granules of which it is

composed in narrow, approximately parallel bands, or layers (Fig. 67). The banded structure gives it the appearance of a stratified rock, but the granite-like colour and the crystalline aspect of gneiss are convenient features of identification. Gray and reddish gneisses are among the commonest of the boulders and pebbles scattered over southern Ontario. The rock masses from which these have been derived form a considerable portion of the Laurentian rocks, particularly in the Muskoka region.

Aeolian Rocks

119. The origin and the properties of aeolian rocks.—This group comprises rocks formed from materials drifted together by winds (*Aeolus*, God of the Winds), and more or less compacted into rock masses. They originate as loose, unconsolidated masses, with less definite stratification than aqueous rocks possess, although both aeolian and aqueous rocks may be classified as stratified rocks. Consolidation of these loose masses may afterwards take place by compression and the deposition of cement materials similar to that which takes place in the solidifying of aqueous rocks. The chief representatives of the group are *sand-dunes*, and *loess* formations. The latter are illustrated by the fertile clay-beds of Central China, and by extensive areas of the valleys of the Missouri and the northern Mississippi Rivers.

Practical Exercises

To study the rocks in a stone pile.—Appliances—A bottle of hydrochloric acid, a hammer, and a hand lens for each pupil.

During an excursion examine the boulders in a stone pile and classify them as (1) aqueous rocks, (2) igneous rocks, (3) metamorphic rocks.

Identify the granite, shale, gneiss, trap, limestone, and conglomerate boulders.

Make a school collection of all the varieties of rocks found within five miles of the school.

Courtesy of Department of Mines, Ont.
Fig. 67 (*a*).—Fault in rock, Hollinger mine, Northern Ontario

CHAPTER XI

THE WEATHERING AND EROSION OF ROCKS

Preliminary Experimental Work

(*1*) *To show that heat promotes chemical reaction.*—

Mix in a test-tube a small quantity of ammonium chloride with twice its weight of quicklime. Smell the gas that is formed. Heat the mixture slowly over a flame. Carefully smell the gas that is given off. In which case is the greater quantity of gas given off?

(*2*) *To illustrate capillary action.*—

Fill a shallow dish to a depth of one-quarter of an inch with red ink. Place a rectangular piece of loaf-sugar on end in the ink. What change takes place in the sugar?

Set a flower-pot filled with dry soil in a pan of water. Does water rise through the soil?

(*3*) *To demonstrate the expansive force of freezing water.*—

Prepare a mixture of salt and crushed ice, or snow, in the proportion of one part of salt to four parts of ice. Fill a small screw-top phial with water and screw the stopper down tightly. Place the phial of water in the freezing mixture and keep it covered with the mixture for ten minutes.

Examine the phial and its contents.

(*4*) *To demonstrate the unequal degrees of expansion of metals under changes of temperature.*—

Heat a bar that is formed of a strip of copper riveted to a similar strip of iron.

Describe the change of shape of the rod. Which surface is the longer, the convex or the concave? Which metal is on the convex surface? Compare the amount of expansion of the two metals.

The Weathering of Rocks

120. Evidences of weathering.—All objects upon the earth are undergoing continual change from youth to old age, from strength to weakness, from freshness to decay; but these changes take place so gradually that usually it is only when we compare the old with the new that the stages of deterioration are observed. The pocket-knife that has been used for months appears to its owner to be as bright as when he purchased it, but he is startled upon comparing it with its mates which are still lying in the shop window. The granite pillar that has been exposed to the weather for a few years still retains smooth surfaces, but they lack the mirror-like polish of its recently erected neighbours; and close examination shows that tiny holes have appeared on the surface, and edges that once were sharp have become rounded. The massive fence that was built thirty years ago, with iron posts set deep into the ground, appeared as enduring as time itself, but now it totters on broken joints, and, where the heavy posts entered the ground, the metal is reduced to masses of thick scales of reddish rust. These and many other familiar instances teach us that even the hardest of materials, including stone and iron, are destroyed by a slow but certain process of decay when exposed to the action of the elements.

121. Weathering forces.—The process of rock decay is usually called *weathering*. This term implies that the principal forces that cause the destruction of rocks are directly or indirectly connected with the phenomena of

weather. In its present application its meaning is extended to include the activities of agencies such as animals and plants, that are only in a very indirect way related to weather conditions. The three agencies that are most effective in producing rock weathering are *water*, *atmospheric gases*, and *organisms* (animals and plants). Although it will be necessary to deal with these agencies separately, it must be understood that there is a close relationship in their activities.

122. Weathering by water.—The solvent action of water upon such materials as salt, sugar, and alum is well known, and it is also commonly recognized that the quantity of these materials that is brought into solution increases in direct proportion to the volume of water that is used. But the fact that water can dissolve many substances, such as glass, rocks, and metals, that were formerly regarded as insoluble, was revealed within comparatively recent years by means of electric tests. It is true that relatively small quantities of these so-called insoluble substances are dissolved, amounting, in the case of limestone, to 13 gms. of limestone in 1,000,000 gms. of water. Nevertheless, given an unlimited quantity of water with extensive contact between the water and the rock, and the quantity of the latter which can be brought into solution may be very great. It is evident, therefore, that in humid climates the solvent power of water will play a very important role in rock removal, provided the water can get into free contact with the rock surface. The contact is furnished not only by the exterior surfaces of rocks, but also by the many joints, faults, fractures, and bedding planes (Sec. 98) which extend the surface of contact to the blocks in the interior of the rock, and serve as channels for conveying water through the whole rock mass. In addition to these larger openings, rocks possess numerous minute

pores. Some forms of rock, such as sandstone and shale, are so porous that they absorb water quite readily, while others are of such close and firm texture that they absorb water less freely. The drawing of the water deep into the pores of the rock by capillary action creates such an intimate contact between the rock and the water that solution takes place upon a fairly large scale.

123. Frost aids the action of water.—When water freezes in a bottle that is tightly stoppered, the bottle is burst because the water expands while turning into ice. The expansive force exerted by freezing water is enormous. It has been found sufficient to burst cannon that had been constructed to resist the bursting force of high explosives. When the water which fills the joints and cracks of rocks freezes, it splits off pieces varying in size from tiny fragments to large masses. The alternate freezing and thawing of the smaller quantities of water imprisoned in the pores of the rock gradually loosens and displaces the fine rock granules, and finally reduces large quantities of the rock to such a condition that it is easily pulverized. We have only to break with a hammer a pebble picked up at random, to find that the surface is less compact than the inner portion. The difference is chiefly due to the solvent action of water aided by the action of frost. Every gardener knows that, if clay soil is thrown up in ridges in the autumn, the alternate freezing and thawing of the water-soaked clods will thoroughly pulverize the lumps and reduce the whole mass to a powder.

124. Certain gases aid the action of water.—In its descent through the air and through soil that contains vegetable matter, water takes up various gases which increase its solvent power. Chief among these are carbon dioxide and oxygen.

125. Carbon dioxide.—Carbon dioxide is always present

in the air. It is also a product of decaying vegetable matter and is found in soil. Its presence in water greatly increases the capacity of water to dissolve gypsum and limestone rocks. It has been found that water containing this gas will dissolve fifty-fold more limestone than an equal volume of pure water. Although the sparkling water that flows from springs in limestone regions appears perfectly clear, yet, if it is boiled, the limestone it contains settles as a white sediment on the inner surface of the vessel. Logs, sticks, and leaves in streams that are fed by such springs, are usually coated with layers of limestone.

126. Oxygen.—Iron nails, wires, and implements that are kept bright and dry will remain unchanged for years; but if they are permitted to become moist, they are very soon eaten by rust. Heavy iron bars that have been used to brace bridges have been reduced to a reddish-brown powder within a few years. Many rocks contain iron compounds; and water, with its dissolved oxygen, penetrates into the pores of these, and oxidizes and removes these compounds. The brown stains frequently seen on the surfaces of light-coloured rocks are due to the effects of these solutions of iron. When sewers and ditches are being dug in our streets and fields, we often find stones of large size composed of coarse, brownish granules, which crumble into sand when struck with a hammer. These "rotten" stones formerly contained iron compounds; but these have been dissolved by water containing oxygen to the action of which they have been exposed for many years, and, just as brick walls from which the mortar has been removed tumble into ruins, so these stones, robbed of the components that bound the particles together, fall into heaps of sand. Stones of the kind just described were plentiful on the surface of the fields of Ontario when these were newly cleared, but the farm implements soon

ground them into powder, which now forms merely a part of the soil of the fields. The fate of these stones illustrates the important fact that the removal of a portion of the components of a solid rock by weathering agents is followed by the crumbling of large masses of rock.

127. The influence of climate upon weathering by water.—Chemical decomposition of rocks by the solvent power of water and the gases it contains is necessarily greatest in moist, warm climates. Warmth and moisture, acting together, not only ensure an abundance of decaying vegetable matter to supply carbon dioxide to the water in the soil, but also provide the conditions suitable for promoting chemical action of the solvents upon the rocks. In many tropical countries this solvent action attains great importance. In Brazil, for example, it is the chief weathering force and has caused the surface rocks to be decomposed to a depth of nearly one hundred feet. In polar regions and on lofty mountains, however, frost is the most important ally of water in promoting weathering. In dry desert regions only a very slight amount of weathering is caused by the action of water.

128. The effect of changes of temperature in desert regions.—Tropical deserts are subject to very extensive daily ranges of temperature. The hot sun during the day frequently heats the atmosphere to a temperature of 120° to 130°F., and rocks, by absorption of heat, are brought to a still higher temperature. The dryness of the atmosphere permits rapid radiation of heat after sunset, so that the temperature frequently falls below the freezing-point. Since rocks are poor conductors of heat, these sudden extremes affect only a thin layer on the surface of the rocks. Just as a sudden change from cold to heat causes glass to crack, so these sudden variations of temperature cause the surface layers of rocks

to become chipped into fragments, which may be easily removed.

129. Weathering by plants.—In order that we may understand the action of plants in bringing about the disintegration of rocks, let us examine the surfaces of the rocks in a Muskoka forest. Here the ridges of rock are almost bare of soil, but the depressions between the ridges contain thin layers of loam.

On the surface of what at first appears to be bare rock, we find circular patches of grayish-coloured lichens. These are plants of a very low type, which have no true roots. The place of roots is supplied by fine projections, called *holdfasts*, which enter the interstices of the rock and hold the lichen firmly to the surface on which it grows. When the lichen is removed, we find underneath it a quantity of fine, moist material of a dark colour, mixed with many small particles of rock. This furnishes evidence that the holdfasts of the plant have burrowed into the interstices of the stone and have extracted mineral foods from the latter, and that the moisture and gases produced by the decay of the plant have hastened the decomposition of the rock.

A rock adjoining the one just examined is found to be almost covered with a layer of moss, which is quite close and thick near the centre of the area, but is scanty near the margin. This phenomenon shows that the moss has gradually extended from a central point, and in time will cover the whole rock. Small flowering plants, such as Canada bunch-berry and blue violet, have taken root among the moss plants, since the layer of soil under the moss is much deeper than that under the lichens. This layer of soil contains considerable sand and coarser materials, which have been derived from the rock by forces arising from the presence of the moss similar to those described in the case of the lichen.

Upon another rock a young pine seedling is growing. The roots, when young, evidently obtained their nourishment from a small patch of black soil that the rain had carried from the mossy bed. But now the roots are penetrating the crevices of the rock, where they find not only moisture, but also vegetable and mineral foods which have been carried there by winds or which have been formed by the weathering of the rock (Fig. 68). In time the growth of these roots will cause them to exert such an expansive force that they will enlarge the cracks in the rocks. At a later stage their decay will furnish acids to aid in dissolving minerals. Possibly, when the tree is full grown, it may be overthrown by the wind, and the roots will uplift tons of rock fragments into the air, where the finer phases of weathering can take place. When the tree finally decays, it will form a fine, brownish soil, which is in part composed of the mineral matter that the roots extracted from the rocks on which the tree grew.

Courtesy of The Macmillan Co.
Fig. 68.—The work of tree roots in weathering

The soil in many of the hollows between the ridges of rock is derived mainly from decayed lichens, mosses, grasses, shrubs, and trees, mingled with the coarser debris from the weathered rocks.

130. The work of animals in rock weathering.—In humid climates, particularly where the soil contains clay, earthworms assist in the work of weathering. Their

burrows constitute channels for the ready transmission through the soil of air and water. Large quantities of soil are passed through the bodies of the worms and raised to the surface as casts. The effect upon the soil is to reduce it to a finer texture and to add to it chemicals that promote solution. On sandy soils and in arid regions, the ant performs a part even greater than that accomplished by the earthworm in humid areas. Burrowing animals of larger size, such as the gopher, hedgehog, badger, and wood-chuck, contribute to the work of soil preparation by exposing quantities of material brought up from deeper layers to the action of weathering agents. Through modern tillage operations man has become one of the chief animal agencies in promoting soil weathering. The removal of trees makes possible a freer movement of water through and over the soil; draining permits air to enter; the plough removes vegetation and turns up loose soil, giving free course to the action of weathering and making possible the erosion of loose material.

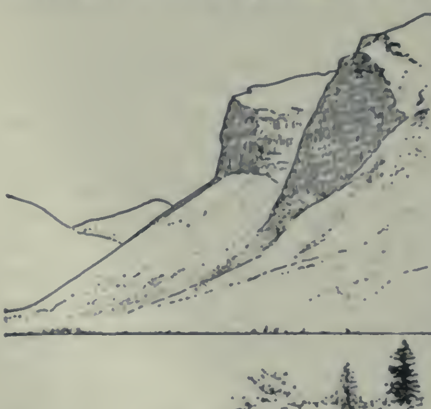
The Erosion of Rocks

131. Co-operation of erosion and weathering.—The process of erosion, that is, the process of scraping materials away from the surface of rocks, works in close co-operation with the process of weathering. Their actions are, indeed, interdependent. The accumulation of even a thin layer of disintegrated rock would suffice to protect the underlying surface from the effects of frost and heat, and would retard the passage of water to such an extent as to interfere materially with the process of weathering; whereas the removal of the decomposed rock exposes fresh layers to the weathering agencies (Fig. 69). The process of erosion, on the other hand, is assisted by the weathering agencies in its work of removing the exposed layers of the earth's crust. By loosening the rock

particles, weathering agencies not only prepare them for removal, but also make them available as tools for the eroding agencies.

Courtesy of the Geological Survey, Canada
Fig. 69.—Bad-land topography on Red Deer River, Alberta

132. Eroding agencies and their tools.—The most important eroding agencies are gravity, water, winds, and ice. These are made much more effective by the loosened fragments of rock, which are used as tools to batter and grind the opposing surfaces.



Courtesy of The Macmillan Co.
Fig. 70.—Talus-slope beneath a cliff

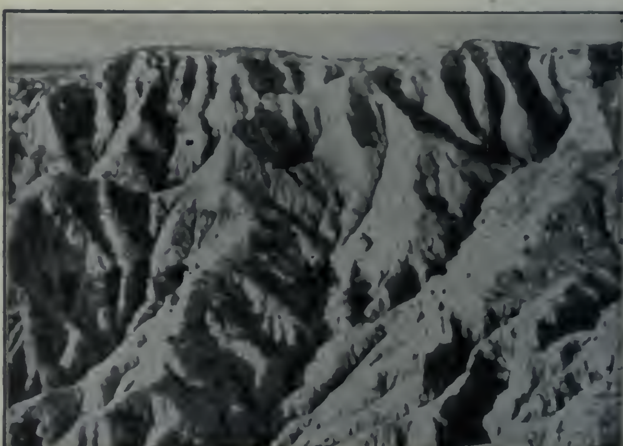
133. Gravity.—Upon the steep slopes of rocks, the force of gravitation is sufficient to effect

the removal of the particles that have been loosened by weathering. When these particles slide or roll down steep inclines or fall upon the faces of vertical cliffs, they knock other particles off and carry them along. The foot of precipitous rocks is usually bordered by a huge pile of this accumulated waste. To such a pile the name *talus* is given (Fig. 70).

The quantity of matter that falls in the way described, depends upon a number of conditions, of which the most important is the activity of the weathering agencies. Hence it is greatest in the spring, when the combined effects of heavy rains and the alternate thawing and freezing have reduced the surface to a very unstable condition. On precipitous surfaces the unstable state of large masses of the earth's crust frequently brings about landslides. The instability may be produced by causes other than those already named. Waves, currents of water, or moving ice, may undermine the base of the cliff, or a heavy fall of snow may make the whole top-heavy. When a mass has been brought to an unstable condition by any of the causes named, a slight disturbance, such as a feeble earthquake tremor, the jarring of a passing railway train, or the shock of a strong gust of wind, may set the whole mass in motion.

Landslides, causing loss of life and destruction of property, are not uncommon in mountain regions. The most destructive landslide of which we have any record occurred in 1903 in British Columbia, at Frank, a town in the Canadian Rockies (Fig. 71). This landslide descended along a front of nearly one and one-half miles and completely obliterated a portion of the town. The momentum of the mass carried it across a wide valley and to a considerable distance up the opposite slope. More than seventy persons lost their lives in this disaster.

Courtesy of the Geological Survey, Canada
Fig. 71.—The Frank landslide, Alberta



Courtesy of Henry Holt & Co.
Fig. 72.—Slope with numerous gullies, the smaller ones joining the larger ones

134. Erosion by water.—Whenever moving water comes in contact with rocks, it exercises an eroding effect, which varies with the volume and the velocity of the moving water and with the character of the rocks. When rain falls upon fine soil, the little streamlets produced by the shower look muddy from their loads of sediment gathered from the soil of the slopes down which they run. When the slopes are steep, gullies are frequently worn into them, and these increase in depth with every rain-storm (Fig. 72).

Erosion by the little streamlet is a type of the work that great rivers are carrying out on a grander scale.

Courtesy of the Geological Survey, Canada

Fig. 73.—The Old or Lower Narrow Gorge, looking up stream, near Lewiston

In Ontario there are a number of rivers that have eroded deep channels in solid rock. A most remarkable example of this is the Niagara River (Fig. 73). A study

of the history written upon the rocks along this river shows that the present gorge has been carved out by the cataract, which has receded from the Queenston escarpment to its present position, a distance of about seven miles. The Canadian Fall is still carving its way up stream, the present rate being 2.3 feet a year.

The scenic beauty of the Grand, Credit, Rideau, Ottawa, and many other rivers, has been produced by their erosive action upon the rocks into which they have cut their channels.

The Grand Canyon of the Colorado is one of the most wonderful examples in the world of gorge formation by a river. For a distance of more than 200 miles the river has cut into solid rock a canyon which is more than 6,000 feet deep, and forms precipices in many places.

Courtesy of the Geological Survey, Canada
Fig. 74—Miles Canyon, Lewes River, Yukon

Impressive though these conspicuous evidences of water erosion are, the total results are insignificant in comparison with the cumulative effects of the removal of loose fragments from the earth's surface by the almost

unnoticed action of rain-wash, and stream and river transportation (Fig. 74). When a large river like the Thames, Ontario, is in flood, the quantity of sediment that is transported by the rushing water amounts to many thousands of cubic feet a day. It has been estimated that the whole land surface of the earth is being lowered at the average rate of one foot in eighteen thousand years. This removal proceeds most rapidly upon steep hills and upon plains with sharp inclines, particularly when these are not protected by vegetation.

135. Erosion by waves.—As we walk along the shores of the sea (Fig. 75) or of our inland lakes, we can scarcely

Courtesy of The Macmillan Co.

Fig. 75.—A wave breaking as it approaches the shore

fail to observe that water waves are important contributors to the work of erosion. Even small waves are seen to keep the grains of sand and the pebbles along the beach in almost constant motion, rolling and swirling them about and causing them to rub and grind against one another. If a storm is raging, these effects are intensi-

fied, even large stones being dashed about and subjected to the process of abrasion.

An examination of these pebbles and larger stones shows that they have shapes and surfaces very different from those of pieces of freshly broken rock. The sharp edges and angles and rough projections of the latter are absent. The rock fragments have been rounded and polished. It is interesting to find pieces of thick glass, such as parts of broken bottles, among the beach debris, and to note that, although these were doubtless broken with the usual irregular jagged outlines, they have been reduced to forms similar to those of the rock fragments. The glass grinder, in this case, is the moving water, and its tools are the pebbles and sand of the shore.

Courtesy of the Geological Survey, Canada
Fig. 76.—Flowerpot Island, Georgian Bay

The particles that are ground off during the process of converting the angular fragments into smooth, roundish disks — the typical form of beach pebbles—constitute the sand of the beach and the clay that is carried away in suspension in the water. The suspended clay will settle in the

course of time, to build up beds of clay similar to those that now form the basis of the fertile soils of many parts of Ontario.

136. The action of waves upon cliffs.—When storm waves dash against the base of a cliff (Fig. 76), the water particles are driven against the rocks with a striking force that is supported by the momentum of tons of moving water. The erosive power of the beating water is increased by fragments of rock which the waves hurl against the barrier. The continual action of these agencies wears hollows and caves into the rocks. If the rock is of uniform texture, large overhanging masses will remain, from which pieces will break off from time to time. As these fragments lie upon the shore, they will be subjected to the solvent and erosive action of water and waves. These effects are illustrated at Scarborough Bluffs, east of Toronto, where wave action is causing the recession of the almost vertical clay cliffs at the rate of about 1.6 feet a year (Fig. 77). When the rocks composing the cliffs are not of uniform hardness, deep caverns may arise from the more rapid erosion of the softer portions, while the harder rocks may remain in the form of irregular arches and pillars.

Courtesy of the Geological Survey, Canada

Fig. 77.—The "Dutch Church," Scarborough

137. Erosion by winds.—We have already seen that winds, by moving clouds and thus influencing rainfall, and by giving motion to water and thus increasing its power of erosion, play an indirect part in weathering and disintegrating rocks. But winds have also a direct effect in altering the surface of the lithosphere. In arid regions the transportation of rock waste depends almost wholly upon winds. Violent storms, in which great clouds of dust darken the sky and overwhelm the traveller with stifling sand, are not infrequent. The grinding and polishing effects of these natural sand-blasts are somewhat similar to those of sand when moved by the waves of the sea. Therefore, in desert regions, where the surface of the land is unprotected by vegetation, wind, with its sand tools, is the chief agent of erosion. The heavier grains of sand are moved along close to the ground,

Courtesy of the Geological Survey, Canada
Fig. 78.—Sand-dune, Sand Bank, Ontario

peck at the bases of the desert rocks, and, by chipping out the softer strata, produce the mushroom and other fantastic types of formation that are characteristic of desert lands.

138. Sand-dunes.—In several parts of Ontario, where the soil is composed of loose sand that supports only sparse vegetation, and also along sandy shores that have fairly constant winds blowing toward the shore, are found peculiar moving sand hills, called *sand-dunes.* Good examples of these are found on the lake shores of Prince Edward County (Fig. 78). Here the landward winds have built up a series of sand-dunes several miles in length, which have advanced inland from one to three miles, and present an almost vertical front about thirty feet in height. These are steadily advancing at the rate of several feet a year, overwhelming fields and engulfing trees that stand in their path.

Standing on the brink of the advancing dune, the observer can discover the cause of the forward movement, in the thin wreath of drifting sand which is swept up the

Courtesy of the Geological Survey, Canada
Fig. 79.—A trough-shaped glaciated valley of Similkameen River, B.C.

gradual incline of the shoreward side, and, falling over the upper edge of the precipitous face, slides down this surface until it reaches a position in which it can come to rest.

139. Erosion by ice.—When ice is set in motion by gravity or by currents of water, it becomes a very important agent of erosion and transportation (Fig. 79). Special attention is given to the effects of ice in modifying the earth's surface in the chapter on glaciers and icebergs.

Practical Exercises

To study rock weathering.—Pay a visit to an old stone wall. What evidences of weathering do you find? What weathering agencies have produced each effect? Are all the stones weathered to the same extent? What kinds of stone are weathered to the greatest extent? In what position are the stones that are most weathered? Account for the greater weathering of some of the stones.

Visit the beach of a lake or a sea and find examples of the phenomena described in Section 135.

After a heavy rain look for marks of erosion on a sloping clay bank or on a cultivated hillside.

Where have the streamlets worn the deepest channels? What effect have the roots of plants in resisting erosion? Where did the streamlets deposit the eroded materials? Account for the sorting of these materials into coarser and finer layers.

CHAPTER XII

UNDERGROUND WATERS

Preliminary Experimental Work

(*1*) *To demonstrate that water tends to seek its level.*—

Arrange apparatus as shown in Figure 80. Pour water into the thistle-tube until the water rises into the bulb of the thistle-tube. Compare the levels of the water in the system of tubes.

Fig. 80

(*2*) *To demonstrate the decomposition of limestone by water containing carbon dioxide.*—

Pass a slow stream of carbon dioxide gas through clear lime-water which has been diluted by the addition of an equal volume of water, until the latter turns milky. Supply each pupil with a test-tube containing a sample of the milky lime-water. Describe the appearance of the lime-water.

Examine a drop under a hand lens and account for the milkiness. Place a few drops on a sheet of mica and evaporate to dryness. Put a drop of acid (dilute hydrochloric is best) on the residue and describe what takes

place. Compare the last reaction with that of acid on powdered limestone. What was the residue on the mica? Pass an excess of carbon dioxide through the remainder of the contents of the test-tube. Explain the meaning of the change in the appearance of the water. Place a drop of the clear solution obtained in the last experiment upon a piece of mica, and evaporate. What is left on the mica?

Or (*a*) Into a test-tube put some finely powdered marble or limestone, half fill the test-tube with distilled water, and shake the mixture gently. Filter a small quantity of the liquid into another test-tube and evaporate to dryness. Set this test-tube aside for comparison with that used in (*b*).

(*b*) Pass a current of carbon dioxide for one hour through the remainder of the mixture prepared in (*a*). Filter into a test-tube a quantity of the liquid equal to that filtered in (*a*) and evaporate to dryness. Compare the inner surfaces of the two test-tubes in which the liquids were evaporated. Account for the difference in their appearance. Put a drop of hydrochloric acid into the test-tube in which the liquid from (*b*) was evaporated. Compare the phenomena observed with those produced by putting a drop of hydrochloric acid on a piece of marble or limestone.

(3) *To demonstrate the formation of stalactites.*—

Prepare a saturated solution of sodium hyposulphite. Partly fill a bottle with the solution and insert a one-holed stopper. Arrange a piece of lampwick to pass through the hole in the stopper and to project part of the way down the outside of the bottle. Examine after several days. Account for the crystals that have formed on the lampwick.

(4) *To demonstrate the effect of changes of pressure upon the boiling-point of water.*

(*a*) Into a strong glass flask put water to the depth of one inch. Heat until water boils briskly. Remove the flame, and insert a one-holed stopper with a thermometer adjusted so that the bulb is immersed in the water.

Rub a cloth dipped in cold water over the surface of the flask. What change takes place in the state of the water? What change in the pressure within the flask is produced by the cold cloth? Read the thermometer.

(*b*) Withdraw the stopper. What change is produced in the pressure within the flask? Does the water continue to boil?

THE ORIGIN AND DISTRIBUTION OF UNDERGROUND WATERS

140. Introduction.—In the last chapter it was shown that surface water, by soaking into the superficial layers of the earth and by its movements in streams and rivers, acts as an important weathering and eroding agent. But, in addition to the water that acts only upon the surface, there are large volumes that penetrate into the earth to depths varying from a few feet to several thousand feet, and that remain there for days, or weeks, or even years. This water plays its part in altering the lithosphere, and by its modes of activity produces some of the most interesting and peculiar of the earth's wonders.

141. The source of underground waters.—When rain falls, a larger or smaller portion of the water percolates through the interspaces in sand or gravel, or pours down the crevices and jointing planes, and runs along the bedding planes of rocks, descending from one level to another until it finds a point of exit in a spring, or until it has filled up all the available space.

142. The quantity of underground water.—The quantity of water that sinks into the earth in the way described, depends upon the amount of rainfall, and also upon the shape and the character of the surface.

If the surface has a steep incline, or if it is composed of clay or other impervious rock, most of the water that falls upon it runs off as surface water; but if it has very little slope, and particularly if it is composed of porous soil or of rock that is cut by many fissures and joints, most of the water passes directly underground.

143. The water-table.—When this underground water has sunk until its descent is obstructed by a layer of clay or other unjointed rock, it accumulates in the strata above the barrier, and these become saturated. The upper surface of the saturated layers is known as the *water-table* (Fig. 81). The depth of the water-table below the

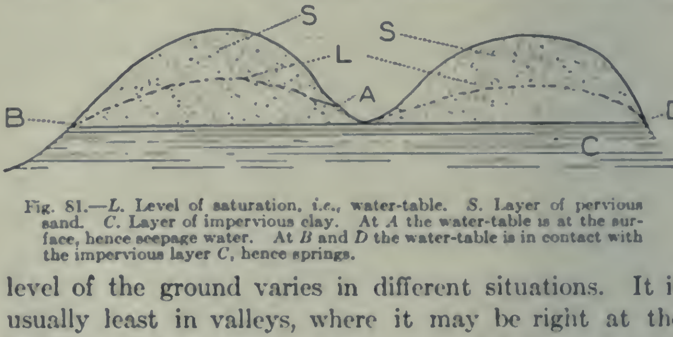


Fig. 81.—*L.* Level of saturation, *i.e.*, water-table. *S.* Layer of pervious sand. *C.* Layer of impervious clay. At *A* the water-table is at the surface, hence seepage water. At *B* and *D* the water-table is in contact with the impervious layer *C*, hence springs.

level of the ground varies in different situations. It is usually least in valleys, where it may be right at the surface of the ground, and greatest on hillsides, where it may not be encountered until the level of the adjacent valley is reached. But even on hills there are often depressions, overlying impervious layers, in which the water-table is close to the surface.

The Phenomena of Underground Waters

144. Wells and drains.—Frequently drains are required in fields, in order that the water-table may be lowered to a

level of three or four feet below the surface of the ground during the season of growth, for very few cultivated plants have roots adapted for growing in and drawing nourishment from a soil that is saturated with water. During dry weather the water-table in many regions sinks lower and lower. This fact has to be taken into account in determining the depth to which wells must be dug. A well must be sunk either below the level of the water-table for the dryest season, or until an underground channel, consisting of porous material through which water is moving to a lower level, is encountered. It is not unusual to find underground streams flowing in tunnels that have been formed by the moving water carrying away the sand and smaller pebbles that lay in its path.

145. Underground caverns. — When underground streams flow down the crevices and joints and along the bedding planes of limestone strata, the water enlarges the channels both by dissolving and by eroding the rocks. Frequently an underground system of streams, similar to surface systems, exists. The main stream, which arises from the union of a number of smaller ones, combines a considerable portion of the eroding power of its tributaries, and thus is able to form large tunnels or caverns. Whenever jointed limestone exists in very thick beds which are not separated by layers of a more porous nature, an abundant rainfall ensures cavern formation on an extensive scale. The limestone rocks of Elora, Owen Sound, Collingwood, and many other localities, furnish examples of caves and caverns of considerable size.

146. The Mammoth Cave.— The most remarkable subterranean cavern of the world is found in Kentucky and is known as the Mammoth Cave. This cavern, or rather system of caverns, consists of a bewildering maze of winding galleries, which show unmistakable evidences of being the subterranean channels of former streams,

many of which have long since dried up or have been drained into lower levels. The galleries have a length totalling at least two hundred miles and vary in height from one or two feet to eighty feet. At intervals the galleries expand into chambers, some of which are so large that a single one could contain a cathedral. The walls and roofs of the passages and chambers are ornamented by stone columns and by pendant cones called *stalactites*.

147. Stalactites and stalagmites.—Stalactites, or stone icicles, as they are frequently called, are formed from the limestone dissolved by water containing carbon dioxide,

Courtesy of Information Bureau, Government of West Australia
Fig. 82.—Stalactites and stalagmites, Yallingup Cave, West Australia

while making its way through minute crevices in the rock. When this solution oozes through the roof of the cave, part of the water evaporates, and some of the carbon dioxide escapes. These changes lessen the capacity of

the water for retaining limestone in solution, and each drop leaves a small deposit. The accumulation of the deposits from a countless succession of drops builds the slender cone that grows downward toward the floor. At the same time the water that drips upon the floor may have some of its limestone still in solution, and so may cause a cone of stone to grow upward. Such a cone is called a *stalagmite.* Frequently the stalactite and the stalagmite grow until they meet and form a column (Fig. 82).

148. Springs.—Subterranean water follows the downward incline of a porous stratum. When the water-table of such a stratum comes to the surface of the earth, the water issues either from a large area, and is known as seepage water, or it gushes out at one point or from a limited area, which is usually where the porous stratum is in contact with an impervious layer (Fig. 81), and thus constitutes a spring. During dry weather the level of saturation of the porous layers frequently falls below that of the point of issue of the water, and the spring dries up until the return of the rainy season. Springs of the latter kind are called *intermittent springs.* The waters of springs are usually clear, because they have been filtered by the sands through which they have passed. They are also frequently cold. The low temperature is caused by the waters having been for a long time so deep within the earth that the surface warmth due to the sun has not reached them.

149. Hot springs.—Waters which arise from depths that are influenced by internal heat are warm, and, in some cases, are even boiling. These constitute *hot springs.* The heat may be that of the general interior of the earth, or it may be heat contained within limited pockets of lava (see Volcanoes, chap. XVIII). Since hot springs are usually found in the neighbourhood of volcanoes, either

active or extinct, the latter explanation appears to be adequate in nearly all instances.

150. Geysers.—There are many curious examples of boiling springs whose activities are intermittent. To a spring of this character the name *geyser* is applied. Geysers are found in only a few localities, notably in

Fig. 83.—"Old Faithful" geyser

New Zealand, Iceland, and in the Yellowstone National Park. In the latter region they occur in large numbers, but each acts independently and with features peculiar to itself. The action of Old Faithful, (Fig. 83),

the most famous of this group, may be taken as typical. For nearly fifty years after its discovery, this remarkable fountain never failed to eject, at intervals of approximately one hour, a column of boiling water and steam that rose more than one hundred feet. This discharge lasted about six minutes. During this period, over seven hundred tons of water were projected into the air. These eruptions are becoming less regular and the intervals longer. The quantity of water thrown out is also less. The eruption is followed by apparent repose, but it, in reality, is a period of preparation for the next explosion.

To understand the action of a geyser, it is necessary to recall that, although water, under atmospheric pressure, turns into steam at 100°C., if the pressure is sufficiently increased, it will remain liquid until the temperature becomes very much higher. The water of a geyser is contained in a very long tube, which is so narrow and irregular that upward movement by convection is very much restricted. The water in this tube is subjected to intense heat, which arises from pockets of lava, as may be inferred from the fact that geysers are always situated in the neighbourhood of volcanoes. The pressure of several thousand feet of superimposed water prevents vaporization until a very high temperature has been reached. Finally, the expansion of the heated water and local formations of steam cause some of the overlying water to be pushed up, and thus the superheated water rises to a level where the pressure is very much reduced. The intensely heated water, when relieved of pressure, bursts into steam with an explosion of tremendous power, and water and steam are hurled forth until the supply is exhausted. During the interval between two explosions the tube is refilled with water,

and this is heated to the temperature necessary to produce the eruption.

The superheated water of geysers dissolves silica and other minerals from the rocks through which it passes, and the deposits resulting from the cooling of these solutions build cones around the mouths of many geysers.

151. Mineral springs.—Moderately warm and even cold underground waters dissolve various materials from the rocks and give rise to mineral springs. Sulphur springs, for instance, contain water charged with gaseous compounds of sulphur; chalybeate springs contain soluble iron compounds; and calcareous springs are impregnated with soluble carbonate of lime.

Courtesy of the Ontario Bureau of Mines

Fig. 84.—Gold-bearing quartz veins cutting conglomerate, Timiskaming

152. Mineral veins.—Occasionally, superheated water and steam containing mineral matter are partly cooled

while rising through cracks in rocks. In consequence of this cooling, the dissolved mineral matter is deposited on the walls of the cracks, thus giving rise to mineral veins. This is only one of the several modes of origin of mineral veins; but many valuable ore deposits, including some of copper, of silver, and of gold, have been produced in this way (Fig. 84).

153. Artesian wells.—In many parts of the world a common method of securing an abundant supply of pure water for domestic and industrial uses is to bore a hole

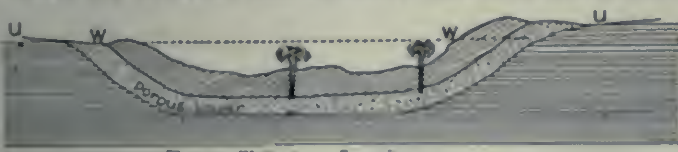


Fig. 85.—Flowing wells in a syncline

several hundred, or in some cases, several thousand feet into the earth. Water, frequently in inexhaustible quantity, rises into the hole, and in some instances throws a fountain high into the air. Such sources of water are called *artesian wells.* Figure 85 illustrates the source and the behaviour of the water. The water which has fallen on the uplands, as at *U* and *U*, sinks into the porous layer, which is composed of gravel, or sand, or chalk, and

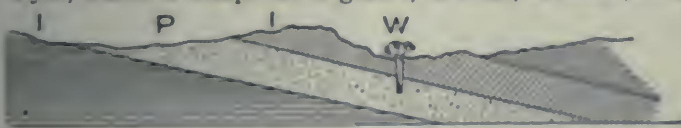


Fig. 86.—Flowing well in a monocline

is inclosed between layers of impervious clay. As there is no escape for the water, a permanent water-table is formed at the levels indicated by the dotted lines at *W*. If a well is sunk through the upper layer of clay into the porous layer, the water from the latter will pour into the well and be forced upward by the head of water at *W.W.*

If the porous material offered no resistance to its movement, the water would rise almost to the level of the water-table; but the material of the porous layer obstructs, to some extent, the water as it moves toward the well, and therefore the water does not rise quite to that height. Another arrangement of rocks which gives rise to artesian wells is illustrated in Figure 86.

I. and *I.* are impervious layers. *P.* is a porous layer. When a well is bored at *W.* the water rises in it because there is a head of water in the porous layer.

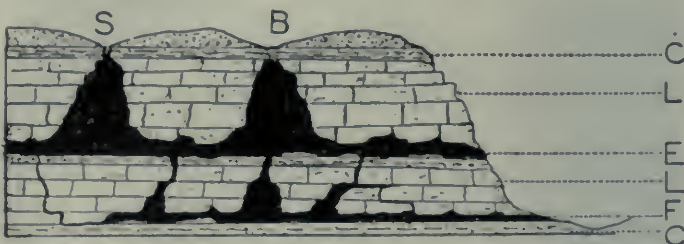


Fig. 87 (*a*).—Diagram illustrating limestone cavern. *S.* Sink holes where water enters. *C.* Clay shale, very slightly soluble. *L.* Thickly bedded limestone. *E.* Entrance to cavern. *F.* Outlet of underground stream.

CHAPTER XIII

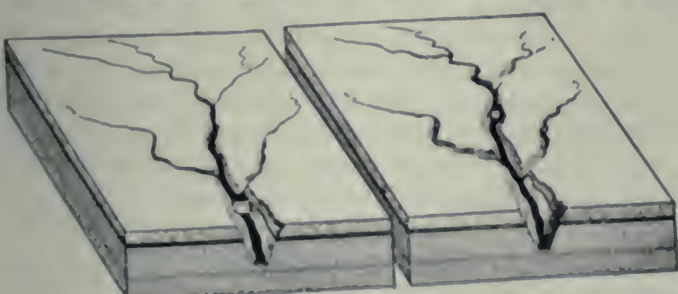
RIVERS

The General Features of Rivers

154. River Terminology.—Almost everywhere upon the earth we find streams of water flowing within well defined borders. When these streams are of considerable size, they are usually spoken of as *rivers.*

The depression within which the water of a stream is confined is called the *channel.* The sides of the channel are known as the *banks* of the stream, and the bottom of the channel is called the *bed* of the stream.

If we follow a stream along its course, we find it joined at intervals by smaller streams, which are called *tributary streams.* Following one of these toward the



Courtesy of The Macmillan Co.

Fig. 87.—A river system, showing channel, banks, and tributaries

uplands, we find that it is joined by a number of smaller tributaries. The main stream, together with its tributaries and their branches, constitutes a *river system* (Fig. 87).

The area drained by a river system is known as a *river basin*. At the margin of the basin is a *divide*, *watershed*, or *height of land*, which separates the waters of adjoining river systems. The divide frequently consists of a range of hills, or of the highest level in a plain or plateau. In the latter case it is often difficult to perceive the exact line of separation of the adjoining river systems. For example, the height of land on the Canadian Shield is scarcely distinguishable from the river slopes on either side of it.

155. The sources of the water of rivers.—During every rain-storm we may observe that streams which have dried up or grown feeble are replenished. It may also be observed that the melting of ice or snow causes freshets. It is, therefore, easy to recognize the direct sources of the water of many streams in rain or snow. But many streams continue to flow during periods of drought, and in spite of the winter frosts that make the soil impervious. A little investigation, however, will show that rain and snow are likewise the source of these streams, only in a more indirect way. Their supplies are obtained either from stores of underground water which issue from springs, or from water that is held upon the flat surface or partly imprisoned within the soft soil of swamps and marshes. These are, therefore, natural reservoirs, fed by rains and snows, from which the waters that keep the streams at fairly uniform levels are gradually doled out.

Usually the waters are supplied to a stream in all the ways that have been described, but there are numerous streams which depend upon one means of supply to a greater extent than upon any of the others. For example, the Saugeen River of western Ontario is fed in large measure by springs that issue from the gravel hills of the river basin, and, consequently, this river has a fairly uniform volume of water. A neighbouring river, the

Maitland, receives a large proportion of its water directly from rainfall and surface drainage, with the result that the volume of its waters decreases greatly in dry seasons.

156. The volumes of rivers.—The volume of a river varies in many instances with the season, changing from a feeble stream or even a dry bed in rainless weather, to a roaring torrent in periods of abundant rainfall. The volume depends, also, upon the area of the river basin. The Humber and the Don of Ontario, for example, although in a region of relatively large rainfall, are small rivers because they drain small areas. In contrast with these, the Ottawa and the Volga, although flowing through areas of no greater precipitation, are larger rivers, because they drain larger basins. A combination of the two conditions, namely, an abundant precipitation, and a vast extent of drainage area, produces the great rivers of the world, such as the St. Lawrence and the Mississippi of North America, the Amazon and the Orinoco of South America, the Danube of Europe, the Hwang-Ho of Asia, and the Congo of Africa.

Forests also exert considerable influence on the volumes of rivers. A greater proportion of the total rainfall is evaporated from cleared land than from that which is protected by the shade of forest trees. Consequently, clearing the land of trees in a certain area diminishes somewhat the volume of rivers flowing through that area. Furthermore, the moss and humus of forest areas absorb and hold water, while fallen trees obstruct, to some extent, the surface flow. Thus forest areas act as reservoirs, in which the water coming from heavy rains or from melting snow is retained for some time. Therefore rivers draining forest areas maintain a more uniform volume throughout the year than do those draining cleared land.

The Work of Rivers

157. The agents that operate in erosion by rivers.—The effects of the water of the spring freshets, as it runs down the furrows of a sloping field, are so commonplace as scarcely to attract our attention. Nevertheless, we can find in them illustrations of the forces by which the rivers and their tributaries are modifying the surface features of continents, by wearing down the mountains and plateaus, by spreading out the plains, and, finally, by transporting the materials from uplands and lowlands out into the seas.

In their work of erosion rivers make use of the mechanical forces that arise from the movements of water, and also of the chemical force due to the solvent power of water. The latter force has already been described in the chapter on weathering (Sec. 122). The importance of this force as a destroyer of rocks is illustrated by the results of a series of tests of the waters of the Thames River, England, which show that the dissolved limestone in this case represents the solution of 140 tons of this rock a year from each square mile of limestone area in the river basin. The mechanical forces that are the direct consequences of the movements of water include the three following:

(1) The eroding force of the currents,

(2) The transporting power due to the movement and the buoyancy of the water,

(3) The cutting and grinding action of the sediment that is being transported.

158. Erosion by the current.—Erosion by moving water is illustrated during every rainfall. The raindrops, by their impact, move the grains of sand and particles of clay, and the tiny rills are discoloured by the sediment washed from the soil over which they flow. The erosive

force increases with the velocity of the current and the volume of the stream, and its attacks are quite effective upon the softer soils. The harder rocks, however, are comparatively unaffected by the action of running water unaided by other agencies.

159. Transportation.—The power of a stream to transport materials depends upon the volume of its waters and also upon the velocity of its current. The speed at which the current flows is determined by several factors. It is greater, for example, upon steep slopes than upon gentle inclines, while upon level plains the movement becomes very slow, for here it depends upon the mass of water moving from the rear and pushing the advance water forward. The rate of flow increases, also, with an increase in the volume of water. This is illustrated during times of flood, when the pressure of accumulating water forces that in front of it onward in a mad rush toward the outlet. Obstacles such as rocks, sand-bars, abrupt curves in the channel, and constrictions of the channel, impede the flow of the water. Hence, the speed of the current is greatest in the middle of the stream, where there are fewer obstructions and where there is no friction with the banks.

The swift currents carry loads of coarse as well as of fine particles. Those having a velocity of one and one-half miles an hour can carry coarse sand. If the velocity is two miles an hour, stones as large as tennis balls are dragged along the bed of the stream. Strong mountain torrents move masses of rock weighing several hundred pounds. When the speed of the current is retarded, the buoyancy of the water alone is unable to support the materials, and they are dropped upon the bed of the channel. The coarser, denser particles are, naturally, the first to be deposited. When the rate of flow becomes quite slow, even fine sand settles from the water and clay

alone remains in it. The clay particles are very minute and remain for some time in suspension even in quiet water, and this gives time for their dispersal over very considerable areas of sea and lake beds.

The total quantity of sediment carried out to the oceans by all the rivers of North America has been estimated as sufficient to lower the level of the whole continent at the rate of one foot in nine thousand years. If it were possible for erosion to continue at this rate, the last vestige of the continent would be reduced to sea-level in about fifteen million years.

160. Erosion by the sediment that is being transported. —Running water that contains no sediment has but

Courtesy of the Geological Survey, Canada
Fig. 88.—Erosion of rocks on Red Deer River

slight effect upon hard rocks, so that even very swift, but clear waters, such as those of the St. Lawrence River, cause very little erosion. The presence of grains of sand, stones, and pieces of ice, however, converts the stream into an efficient grinding machine. These hard materials,

when propelled by a current of even moderate strength, rub and grind against and pound upon the bed and banks of the stream. Slowly but surely even the hardest rocks are abraded by their ceaseless action, and, in this way, gradually the channel of the stream is cut wider and deeper.

161. The formation of gorges.—When a large mound of loose soil, such as that obtained in digging a well or a cellar, is left exposed to the action of rain, its steeply sloping margins soon become furrowed by the streamlets which drain the water from its surface. In the course of time these furrows are cut deep into the mounds, so that they divide the plateau-like area into rough blocks, and tributaries of the main gullies cut the surface into complex patterns. In a similar way, a stream or a river carves a gully in the inclined margin of an elevated

Courtesy of the Geological Survey, Canada

Fig. 89.—Elk River Canyon, B.C., looking southward

area and gradually wears this gully farther back into the interior of the area (Fig. 88).

A deep gully with almost vertical walls is called a *gorge.* When the gorge is of considerable size, it is sometimes spoken of as a *gulch*, and when it is very large, it is known as a *canyon* (Fig 89). The rivers of British Columbia and of the Yukon Territory have cut many gorges and canyons of impressive proportions. The wild grandeur of the rocky chasms and of the foaming waters is one of the most striking sights in the Rocky Mountains.

Courtesy of Ginn & Company
Fig. 90.—The Grand Canyon of the Colorado River

One of the most remarkable gorges in the world is the Grand Canyon of the Colorado. The Colorado River, which has an average fall of about eight feet a mile, has sunk its channel to a depth of from 6,000 to 8,000 feet below the surface level of the lofty plateau across which it flows. The canyon resulting from this erosion extends for more than 300 miles, and through it the river rushes with terrific force (Fig. 90). The swift current and the sediment that it bears are still engaged in

eroding the river bed, and will continue to do so until it is lowered to *base level*, that is, to sea level.

162. The origin of waterfalls and rapids.—In the process of grading its bed to base level, a river occasionally uncovers a portion of a soft layer of rock, which is eroded faster than the harder rocks that overlie it. The gouging out of the soft lower stratum, while the more resistant upper strata remain intact over the upstream portion, results in the formation of a waterfall. A

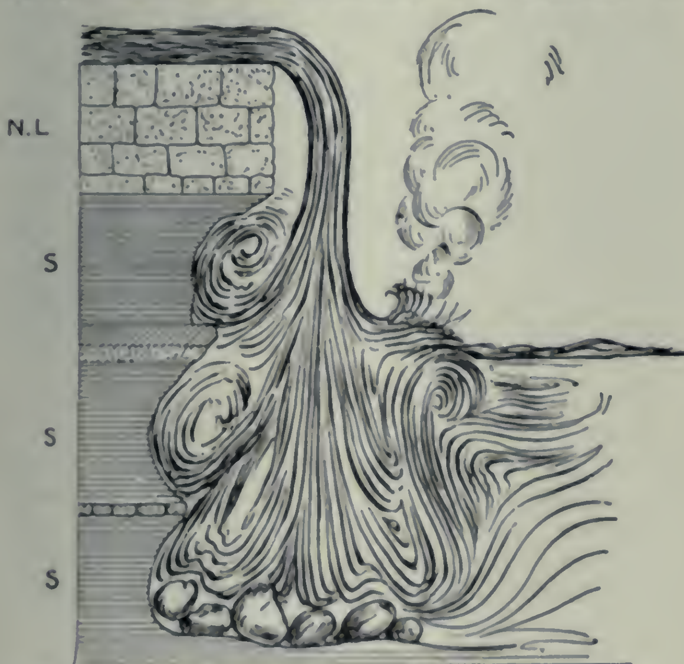


Fig. 91.—Section of Niagara Falls. *N.L.* Hard limestone. *S.* Soft shale with thin strata of limestone

waterfall may also be caused by an original precipitous descent in the channel.

The Niagara Cataract had its birth in the second of

the two ways described, when its waters poured over a vertical cliff near Queenston. This fall has maintained its height and a vertical face throughout the thousands of years since it originated, because erosion, similar to that described as the first mode of origin of waterfalls, has taken place during its whole history. The cliff over which the water pours is composed of an upper stratum of hard limestone and lower strata of soft shales, limestones, and sandstones (Fig. 91). These softer layers are gouged out from beneath the more resistant limestone, until the latter is so undermined that pieces of the overhanging ledges break off because of their own weight and that of the water which rushes over them. Thus, although the Cataract is slowly retreating, it retains its precipitous front.

If the strata underlying the bed of a stream at the point where a waterfall occurs are of uniform hardness, the rock that is the most rapidly removed is that at the brink of the waterfall, where the erosive force is greatest. Such a waterfall will be gradually converted into a rapid, while the continuation of the process will cause the rapid to be cut slowly to a lesser grade, until it becomes merely a swift current. In many cases rapids are due to original steep inclines in the beds of streams. The several rapids of the St. Lawrence River are representatives of this class. At certain places the slope of the river bed is sufficiently great to cause the water to flow with great swiftness, but is not sufficiently steep to cause waterfalls.

The Deposits of Sediment by Rivers

163. Flood-plains.— Although the water of a river is usually confined within the channel, it is not uncommon in times of heavy rain or of sudden melting of snow, for the river to overflow its banks and spread far out over the

surrounding land. Thus is formed a temporary lake of almost motionless water, which almost entirely lacks power for transporting sediment. In consequence, at each overflow a thin layer of alluvial deposit is spread over the flooded land, and the accumulation of deposits builds up a level area known as a *flood-plain* (Fig. 92).

Fig. 92.—A flood-plain, Milk River, near Pendant d'Oreille, Canada

Almost any Ontario stream will furnish examples of flood-plains. These are usually of small size, many being only a few yards wide and containing only a few acres, but the flood-plains of the Grand River and of the Thames River of western Ontario, and that of the St. John River of New Brunswick, occupy quite large areas, which are noted for their rich alluvial soils.

An increase in the quantity of sediment carried by a river, such as may be caused by the elevation of the upper portion of the river basin or by more rapid erosion in the upper basin arising from the cultivation of large areas, frequently causes sediment to be deposited in the channel at the lower part of the river course. The level

of the channel is gradually raised by these deposits, and a succession of overflows accompanying these changes, each contributing a layer of sediment, will result in the flood-plain being laid down to a depth of many feet. At certain places along the Columbia River and the Snake River, for instance, there is evidence of the deposition of sediment to a depth of 360 feet.

164. Beaver meadows.—Before the lands of Southern Ontario were cleared and brought under cultivation, along almost every small stream could be found open glades of very level land, covered with a rank growth of tall natural grasses and bordered by thickets of willow, birch, or poplar. These grassy glades are known as *beaver meadows.* Wherever the beavers built a dam across a stream, a beaver pond would spread over the valley, inundating an area varying in size from half an acre to twenty acres, or even more. Some of the trees standing in the flooded area were cut down by the beavers; the rest soon died because of the complete submersion of their roots. Meanwhile, the pond served as a settling pool for the sediment brought down by the stream. This sediment, together with the remains of trees and aquatic plants, finally filled the pond, and grasses and marsh plants began to grow upon the soft and very fertile soil. Beaver meadows may be seen to-day along certain streams in Old Ontario, and are quite numerous in Northern Ontario and in the forested parts of other provinces of Canada.

165. River deltas.—The deltas found at the mouths of many rivers have their origin in a process somewhat similar to that which gives rise to flood-plains. In delta formation the current is checked by the resistance of the water of the lake or the sea into which the river flows, and this causes the sediment to be deposited quite close to the mouth of the stream. When rivers flow into the

sea, the settling of the sediment is accelerated by the action of the salts in the water. When the tides and currents are not strong enough to sweep the sediment away, it accumulates until a bank is built up almost to the surface of the water. The waves cast the sand and the silt into bars and ridges, and successive floods spread new materials as though over a flood-plain, until at last the delta stands out above the water.

While the form of deltas is usually fan-shaped or triangular (Fig. 93), there are many exceptions. The gradual sinking of a portion of the sea bed on which the delta is being built may alter the shape of the delta or even wholly prevent its formation. The presence of currents which sweep parts of the delta away may have similar effects.

Courtesy of The Macmillan Co.
Fig. 93.—Delta of the St. Clair River

166. Alluvial fans.—Very similar to deltas, though differing in location, are the deposits from streams that descend from mountains which border plains. These streams are usually heavily laden with sediment which has been washed into them by rains or by mountain torrents. Upon reaching the plain the velocity of the stream is checked. The sediment is, therefore, deposited in a delta-like formation which is called an *alluvial fan*. The most favourable conditions for the development of alluvial fans are found at the borders of deserts. Here the volumes of the mountain streams are rapidly diminished by evaporation into the dry air and by absorption

into the thirsty soil. The Piedmont Plain of Southern California, having an area of nearly 200 square miles, is an alluvial fan.

167. Alluvial cones. — Extremely swift mountain streams, which have great power of transportation, deposit quantities of coarser materials close to the point at which they reach the plain, and a cone-shaped mound is built up, which is known as an *alluvial cone* (Fig. 94).

Courtesy of The Macmillan Co.
Fig. 94.—An alluvial cone, near Great Salt Lake, Utah

Since deltas and alluvial fans are composed of sediments, transported by water, their soils are very fertile, and, as they are abundantly supplied with water for irrigation and transportation, they are usually densely populated. Deltas are, however, frequently overwhelmed by disastrous floods. In a single flood that devastated the delta of the Hwang-Ho, China, one million people lost their lives.

168. River meanders.—There is a noticeable difference between the course of a river that has a moderately swift

current and that of one with a slower current. The momentum of the waters of the former gives it power to overcome obstacles, and this tends to keep it straight; while the feeble energy of the latter causes it to be easily deflected from its course. Accordingly, rivers that flow through valleys containing wide flood-plains and having gentle slopes, usually have very sinuous courses.

The formation of the meandering course of a stream is explained by means of Figure 95, in which the dotted lines represent the former banks and the dark lines the present channel of the stream. The current, by striking against the bank at *A*, gradually eroded it, until a strong curve, *C A1 C*, was formed. Meanwhile, the sediment carried by the undercurrents from *A* to *B* was deposited at *B* to *B1*, where the current had its least velocity, and a fairly uniform width of channel was maintained. The deflection of the current from *A* caused it to strike the opposite shore at *D*, and here changes took place similar to those recorded at *A*. In this way systems of winding

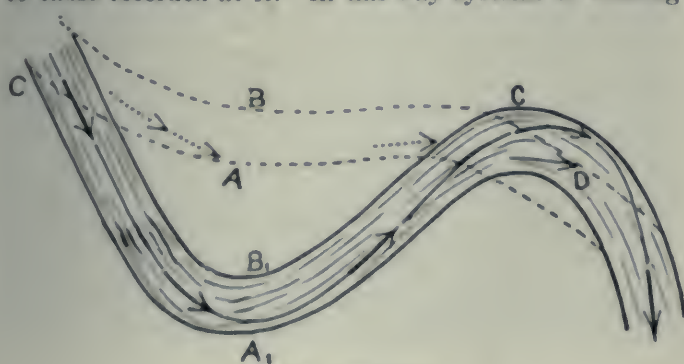


Fig. 95.—Meanders

curves are produced, which give grace and beauty to many valley landscapes. The pleasing effect is increased by the great variety of curves, for no two are ever

exactly alike. The most highly developed type of curve is that which is called the ox-bow. Figure 96 illustrates a series of these curves. Since so much of the erosion in a river meander takes place along the margin, the valley is gradually widened.

Courtesy of the Geological Survey, Canada
Fig. 96.—River meander. The ox-bow

169. River terraces.—After a river has run its meandering course for many years and has spread a broad flood-plain across its valley, it sometimes happens that

the grade of the stream is increased, and its current becomes correspondingly swifter. This change may be due either to an elevation of the upper portion or to a depression of the lower portion of the river basin. Just as a marble, when descending a steep incline, takes a straighter course than that which it follows on a slope of lesser grade, so the rejuvenated stream shortens its curves and begins to carve a narrower valley. Owing to the increased power of erosion arising from the greater velocity of the water, the new and narrower valley is soon sunk below the level of the original broader valley, the margins of which remain as *river terraces* (Fig. 97). A series of changes such as those described above may take

Courtesy of the Geological Survey, Canada

Fig. 97.—Terraces in Columbia River Valley, B.C., Rocky Mountains in the distance

place during the life of a stream, and thus produce a number of river terraces rising one above another (Fig. 97).

170. The life history of rivers and river valleys.—Among the records imprinted upon the tablets of nature,

none are more easily read than those that reveal the life histories of rivers and valleys. The valley begins life as a narrow gorge with precipitous walls, while the stream, during its early years, is a rushing torrent that concentrates its force at intervals into rapids and waterfalls. The stream expends the turbulent energy of its youth in widening the gorge that confines it, in gouging its channel deep and far into the river basin, in lowering waterfalls, and in lengthening rapids, and thus making the grade of the channel more uniform.

The detritus obtained through these operations is used in filling up lakes, spreading plains, and building deltas, while the excess is swept into the sea. In brief,

Courtesy of the Geological Survey, Canada
Fig. 98.—A mature valley, north of Cantley, Que.

the streams are engaged in planing down the rough, unfinished surfaces and in filling up the depressions of the primitive land masses, thus gradually altering the surface features to the lines of maturer age.

171. The maturity of rivers and river valleys.—Mature valleys (Fig. 98) are characterized by relatively smooth surfaces and graceful curving lines, in which concave passes to convex without break or angle. The rivers are quiet, meandering streams, devoid of rapid,

Courtesy of the Geological Survey, Canada

Fig. 99.—Old valley, showing the remains of Mount Johnson

waterfall, or lake expansion. Erosion is confined to the upper portion of the basin, where the tributaries are at work, lowering the uplands, improving the drainage of the heights of land, and narrowing them into divides. The sediment obtained by these erosions is spread out in flood-plains that extend over the lower part of the river course. This period of the life history of a river is a very long one, during which methodical preparation is made for the comparative inactivity of old age (Fig. 99).

172. The old age of rivers and river valleys.—The period of old age of rivers and river valleys is spent in peaceful repose. The surface of the river basin has been levelled almost to a plain, with an occasional

prominence—the remains of a rock mass that proved more resistant to the agencies of erosion than its fellows.

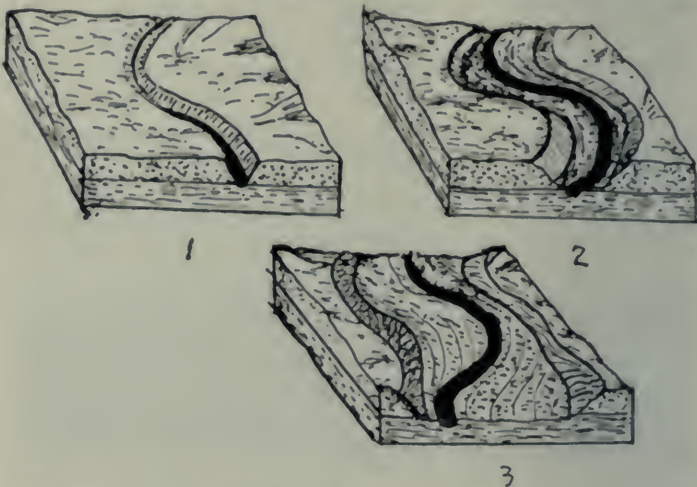


Fig. 100.—Diagram to illustrate a valley broadening by a meandering river. 1. A young V-shaped valley. 2. A valley in early youth. 3. The stream has carved a broad valley.

The erosive force of the river has been reduced to a minimum, because it has cut its channel almost to base level (Fig. 100).

Practical Exercises

Construct a plasticine model of—A local stream, showing its basin, watershed, source, tributaries, and flood plain.

In the local region find examples of: Flood plains, meandering streams, alluvial fans, deltas formed in rain-pools. Compare these local examples with those described in the text.

CHAPTER XIV

LAKES

General Features

173. Definition.—It is customary to define a lake as a body of standing water occupying a depression in the land. If defined in relation to its origin, it must be described as a body of water which is formed where the drainage system of an area is incomplete, or where it has been accidentally obstructed. Lakes are usually in the interior of land areas, but the term is also applied to bodies of standing water that are on the coast and in direct connection with the sea. For example, the large area at the mouth of the Mississippi River, which was once open sea, but is now partly inclosed by bars of sand and silt, is known as Lake Pontchartrain. Even the qualifying word "standing" is not strictly applicable in many cases, for lakes that are expansions of rivers frequently have well marked currents. Thus even the Great Lakes have currents of a minimum rate of four miles a day, and, in some instances, local currents of a velocity of four miles an hour have been observed at parts of these lakes. Nor are all lakes bodies of fresh water, for a few, such as the Great Salt Lake, the Caspian Sea, and the Dead Sea, which, despite their names, are really lakes, contain water which is more salty than that of the ocean.

174. The sources of lake water.—Some lakes receive their entire supply of water from rains that fall directly upon the surface of the lake and upon a narrow rim of

surrounding land. Numerous small lakes occupying rock basins in Muskoka and other portions of the Laurentian area, are representatives of this class.

In addition to this source of supply, many lakes receive water from inlet rivers, and nearly all are fed by tributary streams, just as main rivers are fed by tributary rivers. For instance, the Niagara is the inlet river of Lake Ontario, and the Humber, Don, Trent, etc., are tributary rivers that carry into it the drainage from surrounding areas.

Since the beds of lakes usually lie below the water-table of the neighbouring land, underground water constitutes another source of supply. We have already learned that springs and streams and underground waters all have their origin in rain and snow; hence we are able to trace the water supply of all lakes to the moisture in the air. As a natural consequence of the dependence of lakes upon atmospheric moisture, the levels of lakes are subject to variation.

175. Changes of lake levels.—The amount of water in nearly all lakes changes from time to time. The levels rise after heavy rains have fallen or after much snow has melted, and sink in periods of drought. These changes are greatest in the case of small lakes which have narrow outlet streams. The high level reached during spring freshets may be marked by lines which are caused by the abrasion of ice and which are easily traced along the rocks several feet above the summer level of the water. Such lines are familiar features of the Rideau, Kawartha, and Muskoka Lakes. In the Great Lakes these fluctuations are less noticeable, for they seldom exceed one and a half feet.

In addition to changes arising from variations in rainfall, the levels of the larger lakes are influenced by wind and by atmospheric pressure.

When winds prevail from any quarter for several days, they tend to heap the water against the windward shore. Thus a gale blowing from the north has been known to raise the level of Lake Michigan seven feet at Chicago. The difference between high and low-water marks at the eastern end of Lake Erie is fifteen and one-half feet, high level, in this case, being caused by prolonged winds from the west, and low level, by continuous east winds.

It has been observed, during calm weather, that a high barometric pressure over one part of the lake causes an uplift of the water in a part of the lake over which the pressure is low. In some instances changes in level of several feet have been noted. A series of up-and-down movements follows one of these uplifts until equilibrium is restored. The name *seiche* (sash) is given to such an oscillation of the surface of a lake.

Feeble tidal waves have been observed in the Great Lakes, but in no case have they been found to reach a height of more than five inches.

The levels of the Great Lakes are subject to periodic variations. Thus, during the year 1908 the mean height of Lake Ontario above sea-level was 248.6 feet. During the next two years, the level fell, until in 1911 the mean was 245.6 feet above sea-level. An upward swing followed, and in 1913 the mean level was 248 feet. The last low-water mark was in 1926, when the mean level was 245 feet. This is the lowest level reached since 1895, when the mean was 245 feet. Since 1926 the level has been gradually rising, the mean level for 1929 being 248.2 feet. This was the highest mean since 1908, and was exceeded by only four in the past seventy years.

The Origin of Lake Basins

176. Classification of lakes as features of drainage. —Several systems of classification of lakes have been used by geographers, but the most simple and, at the same time, the most scientific is that employed by W. M. Davis. His classification recognizes lakes as features in drainage systems, as "incidents in the life histories of rivers and river valleys." It may be described in outline as follows:

1. New-land lakes. — This group is composed of lakes whose basins have been recently laid down by glacial action, or consist of original depressions in lands newly elevated above the sea. The land around these lakes bears the rough, unfinished characteristics of youthful areas, and the lakes are, in themselves, evidence of the newness of the lands, since they show that the drainage systems have not been perfected.

2. Lakes due to normal drainage development. —During the development of drainage systems numerous lake basins are formed. Some are produced by streams eroding depressions in which water accumulates (Fig. 101), and others are caused by streams depositing detritus in such positions that dams are formed and large areas become flooded.

3. Lakes due to interference with normal drainage development. —The progress of normal drainage development is sometimes impeded by crustal movements, volcanic activities, or other agencies, which cause portions of drainage areas to become converted into lake basins.

New-land Lakes

177. Lakes on glacial drift.—The new-land deposits of glacial drift which lie south of the Laurentian Highland in Canada and which extend across Minnesota and

Dakota, are strewn with lakes which occupy depressions that were caused by the irregular spreading of glacial detritus. The total number of these lakes must exceed one hundred thousand, and they range in size from small ponds to bodies covering hundreds of square miles. Lake Winnipeg, having an area of more than 9,000 square miles, is the largest surviving lake of this new-land area, and is a vestige of the gigantic glacial lake known to geologists as Lake Agassiz.

178. Lakes on land newly elevated above the sea. —Lakes occupying depressions that existed in lands when these were elevated above the sea are found in Florida and also south of Hudson Bay. Great Salt Lake, Utah, is a remnant of a great body of water that filled a depression in a vast area that arose out of a sea of relatively recent age.

Lakes Due to Normal Drainage Development

179. Ox-bow lakes. It frequently happens that, at times of flood, the water of a meandering stream flows across a narrow neck, such as *S T*, Figure 101. At each overflow this more direct course is worn deeper, until finally it becomes a permanent part of the channel The curve is converted into an ow-bow lake, when its ends become choked with sediment.

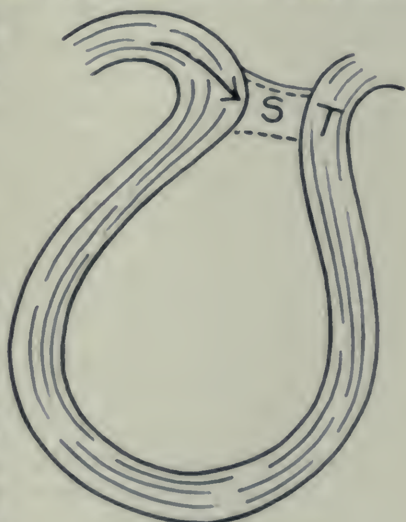


Fig. 101.—An ox-bow lake

180. Flood-plains converted into lakes. — When a stream in flood spreads over its valley, its load of sediment is deposited most abundantly close to its channels, because an immediate check is given to the current as it crosses the banks. In consequence of this, natural embankments or levees are built, which prevent free drainage of the flood-plain, and so lakes are formed on each side of the stream. Tributary streams discharge their waters into these levee lakes and increase their volume. Many shallow lakes of this type are found along the rivers that flow into the Gulf of Mexico. The marshes and the ponds that border many low-land streams of Ontario had their origin in a similar way.

181. Lakes due to dams of delta origin.—In some instances waves and currents move a portion of the sand and silt that are being formed into a delta and build it into bars that inclose considerable areas of the sea. Lake Pontchartrain at the mouth of the Mississippi, having an area of 600 square miles, has been inclosed by bars built from materials filched from the river delta.

When a tributary stream carries large quantities of sediment into a main stream, and the current of the latter is slower than that of the former, the sediment is deposited below the point of confluence, and a dam is eventually raised, which converts the valley above it into a lake basin. Among the best examples of lakes held by delta-fans that have been built by lateral streams, are those that occur in the valleys draining to the Assiniboine and other rivers of Manitoba.

When a stream that enters a lake or a sea crosses low sandy beaches, waves and currents tend to check the progress of the water before it passes the outlet. Here its load of sediment is deposited and is moulded by waves into bars which form a dam. The imprisoned water spreads over the flat lands bordering the stream, thus

forming a lake or a marsh. Numerous lakes and marshes formed in this way are found along the shores of Lakes Erie and Ontario.

Lakes Due to Interference with Normal Drainage

182. Introduction.—The normal processes of drainage development are obstructed by many different agencies. The interferences vary in magnitude from minor movements, such as landslides which obstruct small streams and give rise to shallow ponds, to those involving the folding of large areas of the earth's crust and contributing to the formation of some of the world's greatest lakes. The basins of the Great Lakes of North America are due in part to settling, during folding, of large masses of the earth's crust.

183. Lakes due to crustal movement.—It has been shown in preceding chapters that some parts of the earth's crust are being slowly uplifted, while others are being depressed. These movements may cause a valley to be raised or lowered at one end in such a way that the drainage of the valley is impaired and it becomes a lake basin. Lakes Geneva and Constance in Switzerland have been formed in this way by warping movements of the valleys of the Rhine and the Rhone.

Fractures sometimes occur in the earth's crust, followed by faulting of one side of the broken strata. The depression that is produced by these movements may become the basin of a lake. Numerous basins of this character are found in California. The long, deep, narrow lakes of Palestine, known as the Dead Sea and the Sea of Galilee, had their origin in the settling of strata between two parallel fault planes, Figure 131. These movements usually take place slowly, and in humid

climates the elevated margin is usually eroded so rapidly that a lake basin is not formed. It is for this reason that lakes of this kind are almost entirely limited to arid lands.

More rapid crustal movements, accompanied by earthquake shocks, have caused the depression of surfaces and converted them into lake basins. In 1811, during an earthquake in the Mississippi Valley, a forest-clad area of 120 square miles was depressed to form the basin of Reelfoot Lake, Tennessee. The trunks of the trees of the forest may still be seen standing in the water of this lake.

Fig. 102.—Crater Lake, Oregon

184. Lakes due to volcanic agencies.— Lava flows have sometimes obstructed river valleys and turned them into lake basins. In Iceland, in 1783, lava to a depth of several hundred feet flowed across the course of a stream occupying a broad valley, and the waters rose, forming a

lake which completely inundated the valley and destroyed several villages.

Crater Lake, Oregon, is an almost circular lake, having an area of approximately twenty-five square miles and a depth of nearly 2,000 feet. It occupies the depression made by the falling in of the bottom of the crater of an ancient volcano. The rim of the crater encircles the water and rises almost vertically above it to heights varying from 900 to 2,200 feet. It is classed among the natural wonders of the world (Fig. 102).

185. Lakes due to glacial agencies.—Glacial action has so widely interfered with normal drainage that it has probably given rise to a greater number of lake basins than any other agency.

Glaciers that flow through mountain valleys sometimes cross the courses of streams, and so obstruct the waters that the valleys of these streams are turned into lake basins. An interesting example of this is found in the Stikine Valley, in northern British Columbia. Here a lake which receives the drainage of several glaciers is held within a valley about one mile wide by the Dirt Glacier, which is moving across the entrance to the valley. The outlet of the lake is through a tunnel in the ice. Sometimes this tunnel is suddenly enlarged and the lake basin is emptied.

Numerous lakes have been formed by the choking of the valleys of streams by glacial drift. This obstruction of preglacial valleys by deposits of drift was one of the causes contributing to the origin of the Great Lakes.

When glaciers melt, the water that is formed is sometimes imprisoned between the end of the glacier and a height of land, and thus a lake is formed within this basin. The glacial lakes, Agassiz and Ojibway, which are described in Section 275, were produced in this way. And many lakes of similar origin exist in connection with

the glaciers of the present age. Beautiful Lake Louise in the Canadian Rockies has such a basin, the narrow outlet of which has a dam of glacial drift.

In the Canadian Shield there are thousands of small lakes the solid rock basins of which were scooped out

Courtesy of Royal Canadian Air Force

Fig. 103.—Lake Louise

by glaciers during the Glacial Period. Not only was the loose soil removed by these gigantic scrapers, but even the hardest rocks were abraded by sand and rock fragments contained in the moving ice until the furrows were made smooth and deep.

The so-called pit lakes are among the most interesting varieties of glacial lakes. These have deep walls and are surrounded by level plains. During the glacial age, thick masses of ice were buried beneath sand and silt distributed by glacial streams. When this ice melted, deep pits filled with water were left.

How Lakes are Destroyed

186. Lakes are destroyed during drainage development. —Lakes are transitory features and are continually under the attacks of forces that are labouring to improve drainage systems.

Courtesy of Ontario Bureau of Mines
Fig. 104.—Bond Lake, Ontario

The sediment-laden waters that pour into a lake drop their loads upon mingling with the standing water, and the lake basin is gradually filled with these deposits, to which is added the detritus eroded from the shores by wave action, together with the remains of aquatic plants. While these changes are going on within the lake itself, the outlet stream is engaged in sinking its channel deeper, and thus the surface level of the lake is gradually lowered.

187. The origin of salt lakes.—In arid regions, the amount of water that is evaporated from a lake may

so far exceed the quantity that is supplied to it, that the level of the lake is finally brought below that of its outlet. Such a lake, in the course of time, becomes a salt lake, because the saline matter carried into it does not pass off by evaporation.

The history of Great Salt Lake, Utah, may be cited in illustration of these changes. This lake, which at present has an area of only 2,200 square miles and a maximum depth of forty-six feet, is the remnant of a great lake known to geologists as Lake Bonneville. Distinct beach terraces show that the ancient lake had an area as great as that of the present Lake Huron, and had, in some places, a depth of more than 1,000 feet. Its waters were then fresh, and it had an outlet by the Snake River to the Columbia. A decrease in the amount of rainfall over its basin caused a gradual reduction in the volume of its waters. After the surface had sunk below the level of the outlet, the water of the lake began to grow saline, and, in its present state, contains such large proportions of common salt, gypsum, sulphate of soda, and other chemicals, that it is very salty and bitter.

The Great Desert of Gobi, in China, is the bed of an ancient salt lake. Only here and there can a vestige of the waters of this old lake be found, in the form of a small salt pond or marsh.

Practical Exercises

Examine the dried-up beds of pools that covered parts of a grassy field. Find a reason why lakes are gradually converted into marshes and plains.

CHAPTER XV

GLACIERS

Preliminary Experimental Work

The effect of change of temperature upon the density of water.

Fill the cylindrical vessel of a Hope's apparatus with water cooled by the addition of snow to a temperature of about 8°C. Fill the surrounding chamber with a mixture of snow or chopped ice and one part of salt. Read the upper and the lower thermometer every two or three minutes until one of them registers zero, adding more of the freezing mixture, as needed. Since the densest water is always at the bottom, determine at what temperature water is densest. Alternative method—By the addition of ice or snow, cool water in the cylindrical vessel until it is at 0°C. throughout the liquid. Remove any excess ice or snow. Read every two minutes the temperatures of the upper and the lower thermometers.

Ice in Lakes and Rivers

188. The pushing action of ice.—In autumn, as the weather becomes colder, the temperature of the water in rivers and lakes gradually approaches the freezing-point. As has been shown in the experiment above, water is densest at a temperature of 39.2°F. or 4°C., and so the warmest water of a lake or a pond remains at the surface until this temperature is reached. As soon, however, as the surface water is cooled to this degree, it sinks to the bottom. This process continues

until the temperature throughout the whole mass is 39.2°F. The temperature of the top layer now drops to the freezing-point, while the lower, heavier water at the bottom remains at 39.2°F. Accordingly, the surfaces of small lakes and ponds freeze over readily, and, if the water is only a foot or two deep, they may freeze to the bottom. Large lakes in temperate regions, however, rarely freeze over, for such large bodies of water have absorbed so much heat during the summer that all the water in them does not fall to 39.2°F. during the winter. Near the margin, where the water is shallow, it is possible for the water right to the bottom to cool to 39.2°F., and then the temperature of the surface water rapidly falls to the freezing-point and a layer of ice forms. The constant wave motion on large bodies of water also helps, by breaking up the ice as quickly as it forms, to prevent the water from freezing over.

The ice on lakes and rivers in southern Canada seldom attains a thickness of more than one or two feet. Ice, like most solids, contracts when its temperature falls and expands when its temperature rises. If very cold weather occurs after a lake or a river has frozen over, the ice contracts. As a result of the contraction, either great cracks are formed in the ice or it pulls away from the shore. The formation of these cracks is accompanied by loud noises. Water from below wells up in the cracks or between the ice and the shore and freezes there. Consequently, when the temperature rises and the ice expands, it either bulges up, or more frequently pushes its edges up on the beach. Any stones that are on the shore or that are frozen into the ice near the margin are pushed higher up on the shore. As this alternate contraction and expansion of the ice may continue all winter, in time a ridge of boulders, called a *shore wall* or *ice rampart*, is formed a little distance back from the margin of the lake

or the river (Fig. 105). Such ridges of stones may be seen along the St. Lawrence River and around many of the smaller Canadian lakes.

Courtesy of the Wisconsin Academy of Science
Fig. 105.—View of ice rampart, Lake Mendota, Wisconsin

189. Ground-ice.—It has just been stated that the surface water reaches the freezing-point sooner than the water at the bottom. Under certain conditions there occurs the peculiar phenomenon of ice forming at the bottom of a stream while none is formed at the surface. Such ice forms on boulders or pebbles and is called *ground-ice* or *anchor-ice*. Professor Barnes of McGill University has made a special study of the formation of such ice. It frequently forms in streams with a rapid current if the water is clear and shallow. It will not form if the bed of the stream is shaded, as by a bridge or a

surface layer of ice. It forms most readily on dark stones and usually collects on the pebbles or boulders during the night. It is a slushy, flocculent ice (Latin—*floccus*, a lock of wool), which, if formed in large enough quantities on pebbles, may lift them to the surface and transport them down stream. On the bed of Lake Erie there is much gravel that has probably been transported in this manner.

The formation of ground-ice is probably due to the rapid radiation of heat from the boulders in the bed of the stream. In a clear, unshaded stream these stones, especially if of a dark colour, radiate their heat rapidly at night and cool below 32°F. Then the thin layer of water in contact with them freezes. During the day the stones are warmed by the sun's rays, and the ground ice is loosened and rises to the surface.

Glaciers

190. Snow-fields.—In southern Canada all the snow that falls during the winter is usually melted by April, though in deeply shaded places some may linger until May. If the amount of snow that falls during the winter were to increase, or if the temperatures of spring and summer were lower, the snow would not disappear until later and might remain even to June or to July. Imagine the snowfall still further to increase, and the summers to become still cooler and shorter. Finally, a condition would be reached in which all the snow of the last winter would not be melted when the first snowfall of autumn occurred. At the end of the next summer there would be not only the residue of the last winter's snow, but also the residue left from the winter before. Evidently, as time went on, the accumulation of snow would become very great.

The conditions just described are found on many mountains. The greater the altitude of a mountain, up to a certain limit, the more abundant is the snowfall, and the shorter and cooler is the summer. Above a certain height on such mountains there will be snow throughout the year. This lower boundary of the snow is called the *snow-line*, and the accumulation of snow is called the *snow-field*. At the equator the snow-line is very high, but as the latitude increases, the altitude of the snow-line decreases, until within the Arctic and Antarctic regions it reaches sea-level. The following table gives the height of the snow-line in various parts of the world:

Latitude	Place	Height in feet
80° - 70° N.	Franz Joseph Land	1,000
70° - 60°	Iceland	1,800
60° - 50°	Coast of Alaska	2,500
50° - 40°	British Columbia	4,600
40° - 30°	Asia Minor	11,000
30° - 20°	Southern Himalayas	16,000
20° - 10°	Colombia	15,000
10° - 0°	Venezuela	14,000
	Equator	
0° - 10° S.	New Guinea	14,000
10° - 20°	Bolivia	16,000
20° - 30°	Northern Argentina	15,000
30° - 40°	Central Chile	5,000
40° - 50°	South Central Chile	2,300
50° - 60°	Strait of Magellan	1,600
60° - 70°	Antarctica	Sea-level

Above the snow-line there is an accumulation of snow. The pressure due to its weight gradually forces the lower parts of snow-fields of mountains so that they extend as tongues down the valleys, frequently reaching points far below the snow-line. These tongues are called *glaciers*.

191. Kinds of glaciers.—Streams of ice which extend into valleys and have their sources in the snow-fields above

Fig. 106.—Medial moraine of the Aletech Glacier, Switzerland

are called *valley glaciers* (Fig. 106). Many of these are found in the Selkirk Mountains of British Columbia.

Courtesy of the Geological Survey, Canada

Fig. 107.—Model of Yakutat Bay and Malaspina Glacier, Alaska

If a number of glaciers, moving down parallel valleys, all enter a plain, they may spread out and blend into a single flat mass of ice. Such a mass is called a *piedmont*

glacier (French *pied*, foot, *mont*, mountain, at the foot of the mountain). Many such glaciers are found in Alaska (Fig. 107).

Almost the whole of Greenland is above the snow-line. Accordingly, over nearly its whole surface is a great snow-field, the margins of which are pushed out in every direction. Such a mass of ice, originating, not on a mountain, but over a flat area, whether a plain or a plateau, is called an *ice-cap*. If very large, it is called a *continental glacier*. A continental glacier covers Antarctica—a continent larger than Europe. A similar continental glacier once covered almost all Canada and the northern part of the United States.

192. Valley glaciers.—A valley glacier is composed largely of ice and snow. The snow usually forms only a thin layer over the surface of the ice, but as one follows the glacier back to the snow-fields, the snow becomes deeper. The ice composing a glacier is different in appearance and structure from ice formed by the freezing of water. It has a distinctly granular structure, the granules being sometimes as large as walnuts. The surface of a glacier slopes downward. A cross-section of a glacier shows a convex surface, the curvature being greatest toward the sides. Across the glacier are great fissures, called *crevasses* (Fig. 108). They are caused by the cracking of the ice as it turns laterally around curves or flows over an arched surface. Crevasses may be very wide at the top, and sometimes extend several hundred feet downward into the glacier. They form great obstacles to mountain climbers, and are very treacherous when covered by a recent fall of snow. The glacier is widest high up in the valley and narrows steadily toward its lower end. Valley glaciers vary greatly in size. The average length of the Alpine glaciers is not more than four or five miles, the largest being about ten miles

long and a little over a mile wide. The ice is often from 800 to 1,200 feet thick. The glaciers of the Canadian Selkirks are of about the same size as those of the Alps, but those of the Caucasus, the Himalayas, the Southern

Fig. 108.—The plateau of the Glacier des Bossons, Alps

Andes, and Alaska are much larger, some in Alaska being over fifty miles long.

193. The movements of glaciers.—If a row of stakes is placed across a glacier, it will be found in time that the whole row has moved downward, and it will also be observed that the stakes near the middle of the glacier have moved much farther than those near the margin. The rate at which a glacier moves down through a valley is very slow. One foot a day is an average rate, although some move much faster. It is reported that certain Greenland glaciers move as much as fifty feet a day, but this is a very exceptional rate. The sides and the bottom, which are impeded by friction with the soil and rocks that they are in contact with, move much more slowly than the more central parts. The exact nature of the movement is not fully understood. Undoubtedly gravity and

the pressure due to the weight of the snow and ice are the moving forces. Three factors probably contribute to the motion. First, the weight of the ice above causes the ice at the bottom, which is in contact with the soil and the rocks, to melt, as there the pressure is greatest. This melted ice acts as a lubricant where a lubricant is most needed, namely, at the points of greatest resistance to motion.

Courtesy of the Department of the Interior, Ottawa
Fig. 109.—Glacier in Selkirk Mts., with medial moraine

Consequently, the ice slides over the surface. Secondly, water formed by the melting of the ice flows into fissures and at night freezes. In freezing it expands, thus causing a slight movement forward. As there is much melting and freezing, this must be a potent cause of movement. Thirdly, the ice is granular, and so it is quite possible that a strong, steady pressure may produce a certain

amount of sliding among the granules, and on account of this motion the ice acts like a plastic mass, such as pitch. This is probably the reason why the glacier fits itself into all forms of valleys; for where a valley widens, the glacier spreads out like a river, and again contracts when the valley diminishes in width.

194. Moraines.—As the glacier moves down, much rock, soil, and other debris from the sides and the bottom of the valley move down with it. Soil and rocks roll down from the overhanging sides of the valley and form two lines along its margins. These are called *lateral moraines* (Fig. 106). Where two glaciers unite, the right lateral moraine of one and the left lateral moraine of the other unite to form a *medial moraine* (Fig. 109). Where there have been several unions, a number of medial

Courtesy of the Department of the Interior, Ottawa

Fig. 110.—The Illecillewaet Glacier in Selkirk Mts., showing bottom moraine

moraines may be present. Figure 106 shows a Swiss glacier with a number of medial moraines. Large quantities of debris, due to soil and boulders freezing into the

bottom of the glacier, are carried along by it. This material is called the *bottom moraine* (Fig. 110). The material of all these moraines finally reaches the lower end of the glacier, and, as the ice melts, it is there

Fig. 111.—Glacial scratches

deposited in a great mass composed of material of all sizes, forming a heterogeneous mixture. This is called the *terminal moraine* (Fig. 110). Deposits like these, which are formed by deposition from a glacier, are called *till*, or *boulder clay*. As there is no sorting of material

and no deposition in layers, till is quite different in character from the deposits from running water. From the end of a glacier issues a stream of water (Fig. 110). It may carry away much of the finer materials of the terminal moraine and deposit them farther down the valley. Such deposits, called *fluvio-glacial* deposits, are usually coarsely stratified, and the layers are often uneven and irregular.

195. The work of glaciers.—Ice rubbing against solid rock produces little effect, as rock is much harder than ice. The stones, gravel, and sand that are gathered from the bottom of a glacial valley become frozen into the bottom of the ice, and are tools of great power in the hand of the glacier. As the glacier moves down the valley, these hard, imbedded materials scratch, erode, and grind the underlying rocks (Fig. 111), and are themselves worn and scratched. By this means the sides and the bottom of the valley are deepened, and if the process continues for thousands of years, the deepening may be very great. While a non-glaciated valley is V-shaped, a glaciated valley is U-shaped (Fig. 112). Where there is a central valley with lateral branches opening into it, which have all been occupied by glaciers, a peculiar condition may be produced. While each valley

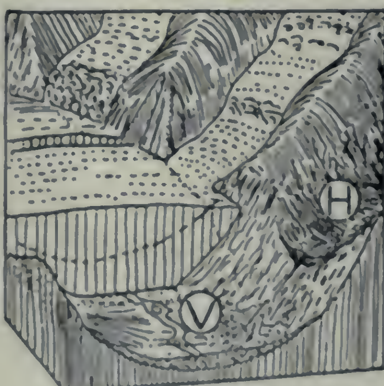


Fig. 112.—Valley (V) and hanging valley (H) left by glaciers

will be eroded and made *U*-shaped, the central valley, since it has much the larger glacier, will be eroded much more deeply than the lateral valleys. When the glaciers all disappear, there will be exposed a very deep, central *U*-shaped valley, with more shallow lateral valleys, the mouths of which open out on the main valley, not at the bottom, but high up on the sides. The mouths of some such lateral valleys are a thousand feet above the bottom of the main valley. Such lateral valleys are called *hanging valleys* (Fig. 112). River-worn lateral valleys in similar situations do not open out on the main valley in this way.

Rocky projections are rounded and smoothed by glaciers, and their surfaces are scratched, the scratches running in one dominant direction. The stones in the bottom of glaciers, which act as its eroding tools, are themselves eroded and scratched. Where the scratches are very fine, the stone is polished. Such stones usually have several flattish faces, which are scratched. Consequently, their appearance is quite different from the smooth, regularly curved, water-worn pebbles, which are found along the margins of lakes or seas (Fig. 113).

Where a valley glacier finally melts, its terminal moraine may form a ridge across the lower end of the valley, and this acts as a dam behind which a lake forms. Ponds and small lakes may also be formed in hollows that have been scooped out by the ice.

196. Icebergs.—The continental glacier of Antarctica, the ice-cap of Greenland, and certain of the valley glaciers of Alaska and Norway extend right to the sea. In such cases the ice forming the extremity of the glacier is pushed forward gradually into the water. The buoyancy of the water exerts an upward pressure upon the end of the glacier, and so huge masses of ice are broken off and float away. Such floating masses of ice broken from the ends of glaciers are called *icebergs*.

The icebergs coming from the glaciers of Alaska and Norway are comparatively small and usually melt away before they drift far from their point of origin. The icebergs from the glaciers of Greenland are often of huge size, being in some cases a mile across and fifteen hundred feet thick. Many of these icebergs, before they melt, are carried southward by ocean currents as far as the banks of Newfoundland. They are a very real menace to trans-Atlantic shipping, and terrible disasters have resulted from ships coming into collision with icebergs in foggy weather. In 1912, the *Titanic* struck an iceberg near Cape Race, and of 2201 people on board, only 712 were saved. The icebergs from the continental glaciers of Antarctica are the largest of all, being occasionally six miles across. They are usually tabular in shape.

Icebergs carry with them the boulders, pebbles, and

Fig. 113.—A boulder deposited by a glacier—Province of Quebec

pulverized rock which their parent glaciers bring down to the sea. When the icebergs melt, these materials drop to the bottom of the ocean. Glacial boulders which

have been transported in this fashion have frequently been brought up in dredging operations in the North Atlantic Ocean.

QUESTIONS

1. The snow-line on the south side of the Himalayas is much lower than on the north side. Why is this so?

2. If a valley glacier descended into the sea, tell what would become of the terminal ice.

3. In what part of the world would be found glaciers extending down to the sea?

4. Can large boulders be transported from their place of origin by any other agents than ice? Explain.

5. A glacier sometimes has longitudinal crevasses. Tell how these may be formed.

6. The water in a glacial stream, such as the Rhone, is sometimes milky in appearance, owing to the very finely divided sediment it contains. What is the probable origin of this sediment?

7. The stream flowing from the base of a glacier may be a rushing torrent late in the afternoon, and at the following sunrise the channel may be almost dry. Explain.

CHAPTER XVI

SHORE-LINES

Forms and Agencies

197. Varieties of coastal forms.—No greater variety of form is presented by any earth features than is to be found in the diversities of coast-lines. To the query, whence come these countless forms, the most direct answer is that they are the products of the agencies that operate in the most changeable and changing line of the earth—the line in which the sea and the land meet. Among the agencies that modify shore-lines, the most important are crustal movements, wave erosion, and sedimentation.

Crustal Movements

198. Evidences of elevation and subsidence.—If the level of the sea is taken as a standard, we shall find that every coast-line bears marks of alterations in its altitude.

The eastern coast of Canada has many features which indicate a subsidence of several hundred feet within comparatively recent geological time. Thus the old channel of the St. Lawrence can be traced south-eastward by soundings across the bed of the present Gulf of St. Lawrence and out to the Atlantic between the islands of Cape Breton and Newfoundland.

Along the cliffs that form the eastern coasts of the Scottish Highlands are horizontal terraces, parallel to one another and at different elevations above the sea. These terraces are covered with sand, pebbles, and marine

shells. Behind them the cliffs are notched or hollowed into caves similar to those carved into cliffs by waves. The terraces are manifestly old sea beaches, and their present position indicates either that the land has risen or that the sea has sunk. Other phenomena go to show that the land of these regions is gradually rising. Figure 114 shows a similar terrace in Alaska.

Courtesy of Henry Holt & Company
Fig. 114.—A wave-cut terrace, Alaska

An interesting example of alterations in coastal level which have stamped their records upon structures raised by man, is found upon the shores of the Bay of Naples. Here in Roman days the temple of Jupiter Serapis was built upon a terrace several feet above the waters of the bay (Fig. 115). Three marble columns of the temple are still standing, but portions of their once smoothly polished surfaces have been roughened by the borings of a mollusc that works only under water. These borings extend upward for a height of nine feet from a line twelve feet above the level of the base of the column. In this way is recorded the subsidence of the temple to a depth of at least twenty-one feet below its original level, and its subsequent elevation to its present height above the sea. The absence of borings from the lower twelve feet

of each column is probably due to the fact that these portions were buried in mud, which served to protect them from the mollusc.

199. The depression of lands of strong relief.—The subsidence of lands of bold relief gives rise to coast-lines of marked irregularity. The shores of north-western

Courtesy of The Macmillan Co.
Fig. 115.—Columns of the ruined temple of Jupiter Serapis, near Naples

Europe and those of Canada are examples of coast-lines that were produced by the depression of areas of bold relief. The elevated parts remain unsubmerged and constitute the long narrow peninsulas and numerous islands, while the valleys that had been eroded by streams and glaciers are now buried beneath the sea and form the beds of channels and fiords.

The settling of the Pacific coast of Canada by the submergence of a long narrow valley that lay between the present Coast Range and the mountains that now run through Vancouver Island, produced the Strait of

Georgia. The higher portions rise above the waters as islands. Farther north are many islands, channels, and fiords, similar to those of Norway. Like the latter, these are due to the subsidence of a coast-land which had once been eroded by glaciers and streams.

200. The depression of areas of low relief.—If the depressed area is one having no lofty mountains and plateaus and deep valleys, the resulting coast-line will contain no prominent indentations, but will be characterized by long, winding curves and flat or gently shelving shores. These shores will, in many instances, be covered with water at high tide, and salt-marshes and mud flats will be common features. Much of the coast of the south of England is of this character.

201. Shore-lines due to elevation.—In the chapter on rivers and also in that on erosion, it is pointed out that large quantities of sediment are being continually carried into the sea by streams. In some instances this sediment is deposited at or near the mouth of the stream, thus forming deltas and off-shore bars. In many cases, however, it is carried some distance out to sea by tides and currents and settles at last over a wide area of sea floor. One effect of the spreading of the sediment is the levelling of the bottom of the sea. Even such irregularities as drowned river-valleys, are, in the course of time, smoothed out by the gradual accumulation of sediment. During this process no stream or wave erosion has been taking place on the sea-bed, except in shallow coastal waters. In consequence of these influences, the portion of the ocean floor that surrounds the margin of the land areas is usually as smooth and regular as a level plain. When such areas become elevated above sea-level, they constitute *coastal plains*. The shore-lines of coastal plains are straight or gently curved, and are devoid of promontories or deep indentations. The shores slope

gradually beneath the sea. The low plains that fringe the Atlantic shores of the eastern United States are composed of sediment that was carried into the sea by numerous rivers, distributed by waves and tides and currents, and, after a time, re-elevated by crustal movement. The coast of the Gulf of Mexico and the eastern coast of Argentina are also composed of deposits from rivers. The straight or gently curved and regular coast-lines, the shallow shore waters, and the dearth of good harbours are evidences that these are coastal plains.

202. The rate of elevation and subsidence. — The elevation or the depression of a coastal zone is, in most cases, a slow process which takes place without earthquake shock or other marked disturbance. So gradual is this movement that it can scarcely be detected, and rivers have time to sink their channels into the coastal plain as rapidly as it is elevated.

There are instances, however, of the sudden uplifting of coastal zones. The latter movements are due to faulting and are accompanied by earthquake shocks. In the chapter on earthquakes will be described the sudden upheaval of a part of the coast of Alaska to a height of forty-seven feet above its former level (Sec. 261). Above the beach terrace that was formed by this uplift, another terrace rises, which is a monument to a similar upheaval a century earlier. Almost the whole western coast of America from California to Chile has a distinct series of such terraces, rising one above another and clearly visible to the voyager along these shores.

Wave Erosion

203. Waves alter Coastal Detail.—In the sections dealing with the role played by crustal movements in forming shore-lines, it is shown that the general trend of coast-lines and their deep indentations, that is, the coast

features that are shown on ordinary maps, are due to elevation and depression. Waves cannot cut such deep indentations into even soft rock. It is found, for instance, that, as the wave-cut inlet advances inland, the force of the waves is more and more expended in friction against the walls and bottom of the indentation, and finally loses its power to cut the inlet farther inland. It sometimes happens that, even before this stage is reached, the sediment cast up by waves and carried by currents is built up as a barrier, protecting the shore from erosion.

204. How waves erode.—The work of the small waves of our inland lakes, in undermining clay banks and in hollowing caves into the rock cliffs along the shores, is sufficiently impressive to arouse our interest. By an exercise of the imagination, we can, in a measure, comprehend the eroding power of the giant ocean waves, which are frequently thirty, and, occasionally, fifty feet in height and travel with a velocity that sometimes reaches sixty miles an hour. When a wave moves toward a shelving shore, the speed of its base is retarded by friction with the sea bottom, and the wave is seen to grow narrower but higher, and the upper part to incline forward, farther and farther, until it "breaks." The "breaker" may reach a height twice as great as that of the wave, and, when it strikes upon the base of the cliff, it strikes with the force of an avalanche. Such waves attack rocks in several ways. Water and air are driven into the grooves and caverns in the rocks with the pressure of miniature rock blasts; pebbles and grains of sand are dashed against the cliffs and bite into them like chisels; while masses of rock weighing hundreds of pounds are hurled with destructive force against the foot of the cliff by the tumbling waters. By these forces the furrows and caverns are deepened until the cliffs are undermined.

205. Wave sculpturing.—When a ridge of rock projects into the sea, it is usually exposed to attacks from either side, according as the storm comes now from this direction and now from the opposite. When such exposed forelands are composed of rocks having many joint planes, the unequal rates of erosion cause them to be carved into a great variety of shapes. The soft rock, for instance, may be eroded from both sides of the foreland until an arch is cut through. In other cases the removal of the softer rocks leaves the harder masses projecting in

Courtesy of The Macmillan Co

Fig. 116.—A stack and a wave-cut arch in a sea-cliff on the coast of France

the form of buttresses. In the case of jointed rocks, the openings at the joint planes give freer scope to the work of rock removal, and these rocks become carved into columns or stacks (Fig. 116).

In the course of time even the hardest rocks must disappear as a result of the attacks of waves, and so we recognize in wave erosion another agency whose final effect is the straightening of shore-lines.

206. Sea caverns.—The most favourable condition for the formation of caverns is a stratum of soft rock at sea-level, overlaid by layers of massive unjointed rock. The cave is hollowed out of the soft rock by wave erosion, and the overlying unjointed rock remains to form the roof.

When the sea at high tide closes the mouth of a cave, the rise and fall of waves may cause such great changes in the pressure of the air imprisoned within the cave that the roof and walls are eventually shattered. In some instances holes are opened, perhaps several hundred feet inland. During heavy storms air, spray, or even jets of water are forced through these "blow-holes."

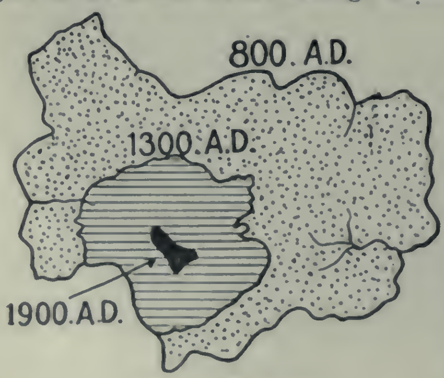


Fig. 117.—Heligoland

207. The rate of wave erosion.—The rate of wave erosion depends upon such conditions as the directness of exposure of the coast to wave action, the protection of the shore by detritus, the hardness of the rock, the depth and the width of the sea, and the consequent strength of the waves.

The destruction of exposed coasts by this agency is sometimes quite rapid. It has been estimated that the storm-swept coasts of Britain are being removed at the

average rate of five and one-half feet a year. The partial destruction, within historic times, of Heligoland (Fig. 117), the once celebrated German naval base in the North Sea, is a striking illustration of the effectiveness of wave erosion upon shores exposed to the sweep of a wide sea. This island is composed of fairly hard sandstone. At the time of the Danish invasion of England its perimeter measured nearly one hundred and twenty miles. At the time of the crusades the perimeter had been reduced to forty-five miles, and from that time it dwindled, until at the close of the Great War it measured only three miles.

Following the German surrender, the concrete fortifications of the island were dismantled, and were soon broken by the ceaseless waves. The destruction of the island is now going on apace, and unless it is protected by artificial means, Heligoland will soon be only a name.

Sedimentation

208. The agencies of removal.— The rock waste resulting from wave erosion is removed by the water, partly in solution, partly in suspension, and partly in fragments that are swept away by moving water. The undertow, which is caused by the water of the spent waves slipping back to sea underneath the incoming waves, is especially active in removing the debris.

209. Terrace building.—Since wave action is seldom effective at a depth that exceeds thirty feet below the surface of the sea, one of the effects of the advance of the sea upon the land is the formation of a shelf, or terrace, under the water along the shore. When the undertow reaches the outer margin of this terrace, it mingles with the calmer waters of the deeper sea, and its load is deposited. By this means the shore terrace is gradually extended seaward.

210. Shore currents and their work.—Owing to the irregularities of coast-lines it usually happens that waves strike projecting points of the shore obliquely, and the waters of the broken waves are pushed along the shore in a more or less irregular course. This movement of water constitutes the *shore current.* The rock particles that have not been carried out by the undertow are borne along by these currents until some variation in the shore-line causes the arrest of the movement, or until a stronger incoming wave dashes the debris a little higher upon the shore, where it is left stranded.

211. Sea beaches.—The accumulation of this stranded debris constitutes a *beach.* When the beach consists of very fine rock waste, it is known as a *sand beach*, but when it is made up of disk-shaped pebbles and stones, worn smooth by grinding against one another, it is called a *shingle beach.* The latter form may be produced where very heavy waves roll high upon a shore, and the undertow carries the finer particles away.

212. The formation of bars.—Owing to retardation by friction large sea waves seldom pass with full force into a bay or a harbour. In consequence of this retardation, a large portion of the sediment which waves have obtained by their own erosive action, or which they have filched from the undertow, is dropped across the entrance to the bay. In this way a *bar* is gradually formed. The position and the shape of the bar are determined by the direction given to the waves as they sweep past the adjacent headlands. Frequently these bars appear above

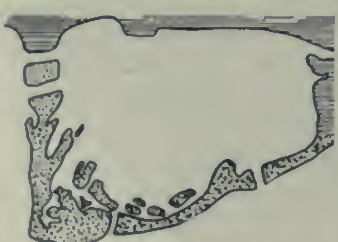


Fig. 118.—The islands inclosing Toronto Harbour. These constitute a "hook" in process of formation

the water as narrow, pointed projections, and are then known as *spits*, or if the point is sharply curved, the spit becomes a *hook* (Fig. 118).

213. Off-shore bars or barrier beaches.—When the shore waters are shallow and there is an abundant supply of sediment derived either from the erosion of loose coastal materials or from river action, waves and currents frequently build bars parallel to the shore, without the assistance of bays. Bars that are formed in this way are known as *off-shore bars*, or *barrier beaches*. The sand peninsula that incloses Rondeau Bay is an example of an off-shore bar that has been built in a fresh-water lake. As a result of the formation of an off-shore bar, a strip of shallow water called a *lagoon* is inclosed between the bar and the shore.

Organic Life and Coast-Lines

214. Salt-water plants.—Some forms of plant and animal life carry on valuable work in furthering coastal changes. In the temperate regions many species of salt-water plants flourish in the quiet waters of lagoons and sheltered bays. The presence of these plants tends to retard all movements of the water and thus to promote sedimentation. The accumulation of sediment supplied by rivers, winds, streams, and tides, together with the decayed remains of aquatic plants, converts the lagoon into a salt-marsh. Gradually the level of the marsh is raised above that of the tidal waters. Flushing by rains removes the excess of salt from the soil, and fresh-water and shore plants displace the marine vegetation.

By building dikes and then draining these marshes, man has converted large areas into tillable land. On the coasts of Nova Scotia, Holland, and England, valuable stretches of fertile soils have been reclaimed in this way. The addition to the area of the British Isles by this means

is far in excess of the loss due to erosion. At Point Pelée and other parts of Ontario, fertile lands have been reclaimed from the lakes in this way.

215. Mangrove swamps.— On semi-tropical coasts mangrove trees replace the salt-water plants of the temperate zones (Fig. 119). These trees grow in dense colonies, with their roots loosely imbedded in the soft mud at the bottoms of the lagoons. Other roots descend from the branches into the water and the mud, and these serve as props to aid in supporting the trunks. The

Courtesy of The Macmillan Co.

Fig. 119.—Mangrove swamp on the coast of Florida

trees increase rapidly in number and in size, and the lagoon soon becomes filled with a dense tangle of roots, which have an important influence in collecting detritus from the water.

The decay of the older trees is as rapid as the growth of the younger, and the lagoon is soon converted into swampy land. Meanwhile, the mangrove colony slowly advances seaward, so that in some cases these jungles have attained a width of twenty miles.

216. Animal agencies.—In the work of shore-line building, animal organisms are scarcely less important than plants. Along the eastern coasts of Brazil are long lines of barrier beaches, which have been converted into solid rock by deposits of limestone formed from the shells of minute sea creatures. Coral structures, such as islands, reefs, and atolls, which are the productions of coral polyps (Sec. 284), are widely spread through the warmer seas. The latter formations are more fully dealt with in the chapter on islands.

Estuaries

217. Definition.—An estuary is the tidal portion of a river, that is, the wide mouth of a river which is so open to the sea that tidal waves move far up the river. The mouths of the Severn and the Thames in England, of the St. Lawrence in North America, and of the Parana in South America, are typical estuaries.

218. The scouring of estuaries.—Since a river tends to deposit its load of sediment at its mouth, an estuary cannot be permanent unless the deposits are removed by some agency. The removal is usually the work of the tide. The rising tide forces the water back into the estuary, but the falling tide, by releasing the accumulated waters, causes such an increase in the strength of the current that its carrying power is far in excess of the normal. To be most effective in promoting this scouring action, the tide must move straight into the estuary. When the tide moves across the mouth of the estuary, it

frequently distributes the sediment in such a manner as to form a bar.

219. Drowned valleys.— The funnel-like shape, so characteristic of estuaries, is due, in some cases, to the scouring action of the tide, but more frequently it has risen from the depression of the coastal portion of the river valley until it was flooded by the sea. A valley which is depressed in this way is known as a *drowned valley*.

Practical Exercises

(1) *Effects of jetties.*—Pairs of concrete or wooden walls extending from opposite banks partly across a stream tend to cause the deepening of the central channel of the river. Account for this effect. An objectionable feature is that the deepening is not uniform, being greatest opposite the ends of the jetties. Explain why this is the case.

(2) When a bar forms at the mouth of a river, the channel may be kept open across this bar by extending the mouth of the river between parallel jetties to the inner margin of the bar. Account for this.

(3) If a jetty is built projecting from the shore of a lake in such a direction that it intercepts obliquely the heavy waves that beat on the shore, a sand beach will be gradually produced along the part of the shore that is protected by the jetty. Account for this beach.

CHAPTER XVII

MOUNTAINS

Mountain Terminology

220. Definition.—A mountain is usually defined as a mass of land the summit of which has only a small area and which rises to a prominent height above its surroundings. According to this description, there is no arbitrary distinction between "mountain" and "hill," nor do geographers recognize any distinction; for it is not unusual to find the term "hills" used in connection with elevations that rise several thousand feet above sea-level, while comparatively small local prominences, particularly when these occur in plains, are called mountains.

221. Mountain terms.—A mountain may consist of a mass of land tapering to a point at its summit, in which case it is called a *mountain peak* (Fig. 120); or it may be in the form of an elongated mass having a more or less continuous crest, and it is then known as a *mountain ridge* (Fig. 121).

A *mountain range* is a series of mountain peaks or ridges that occur in a more or less continuous line.

A *mountain system* is composed of a number of mountain ranges, which may form a long line of mountains, though, in addition to this, they are usually arranged to form a number of parallel or slightly diverging series. (See Rocky Mountain System on map, Fig. 122).

A *cordillera* is a group of mountain systems. Of necessity, a cordillera occupies a large area of country

and so has a very diversified character. The western portion of North America is occupied by the largest cordillera of the world, having an area of 2,300,000 square miles, which is approximately equal to two-thirds

Courtesy of the Geological Survey, Canada
Fig. 120.—Mount Robson

of the area of Europe. The part of this cordillera which is in Canada covers nearly all British Columbia and extends into the Yukon Territory, and includes the Rocky Mountain System, the Selkirk, Gold, Purcell, Columbia, and Coast Ranges, and the Interior Plateau (Fig. 122).

A *mountain pass* is a gap which crosses a mountain ridge or range and affords a comparatively easy passage through the mountains (Fig. 123). Passes are usually formed by the erosive action of streams, which, in their course through depressions in the mountain range,

attack the softer rocks or the jointed formations of the mountain mass.

Courtesy of the Geological Survey, Canada

Fig. 121.—Looking north over the South Thompson River, west of Ducks Station

The Distribution of Mountains

222. The great mountain belts.—In the two following chapters on volcanoes and earthquakes, we shall learn that these manifestations of crustal changes usually occur along two great lines, one girdling the Pacific Ocean, and one encircling the earth about 20° to 30° north of the equator. An examination of the distribution of the great mountain systems of the world shows that they, too, are, for the most part, found in these two zones. These are the lines of greatest crustal movements and of mountain-building.

223. Mountains in relation to continents.—Aside from their arrangement into the two great belts, mountains occur without any special order in their distribution, except that all the continental areas contain mountain systems which play an important role in determining the

outlines and the reliefs of the continents. For this reason mountain systems are usually called the *axes* of the continents. In so far as axis means a physical support, the term is not particularly fitting, for we have

Courtesy of the Geological Survey, Canada

Fig. 122.—Shuswap terrane rocks in south-central British Columbia

already seen that zones of mountain-building are areas of weakness in the earth's crust rather than areas of strength. It would be more correct to speak of the mountain ranges as being the growth centres of the continents, because from them issue streams, which carry sediment eroded from the uplands and deposit it on the lower levels. The greater part of the continental areas have been built up from the detritus obtained from mountains, and, in many instances, the mountains themselves have, in large measure, been produced by the uplifting of sediment derived from the erosion of more ancient highlands. This is illustrated in the history of the Rocky Mountains. These are composed, for the

most part, of limestones, sandstones, and shales, which are the product of sediments that had been eroded from an ancient highland, and deposited, in some areas at least, beneath the sea. Subsequent upheaval, which took place during a recent geological age, raised these strata to even greater heights than those of the present mountains (Fig. 120).

The Origin of Mountains

224. Original and relict mountains.—The history of the Rocky Mountains, briefly stated in the last section, illustrates a mode of origin which is described as origin by *accumulation* and *uplift;* and mountains which began their life cycle in this way are called *original mountains.*

Courtesy of Canadian National Railways

Yellowhead Pass—1920

In contrast with this mode of origin is that of mountains which are produced by the erosion of lofty plateau areas. Mountains which are formed in the latter way are called *relict mountains.*

225. Varieties of original mountains.—Original mountains may be classified as:

(1) Laccolith mountains
(2) Mountains due to folding
(3) Mountains due to faulting
(4) Volcanic mountains.

Volcanic mountains will be fully described in the chapter on volcanoes.

226. Laccolith mountains.—The name *laccol'th* is derived from a Greek word meaning stone cistern, and is applied to dome-shaped mountains which occur singly or in groups, and which were formed by the intrusion of molten rock between weak layers of the earth's crust (Fig. 124). The pressure of the molten mass was suffi-

Fig. 124.—A laccolith

cient to cause the overlying strata to bulge upward and form a dome, but not strong enough to force an opening to the surface. Representatives of this type are found in the Henry Mountains of Utah and in the Black Hills of Dakota. In these instances they exist in scattered groups and rise from three to five thousand feet above the surrounding plateau.

The flat-topped hills in the neighbourhood of Port Arthur, Ontario, had their origin in intrusions of lava. Weathering and erosion have removed the softer strata that originally covered the hard lava rocks. These

intrusions, known as *sills* on account of their flat forms, have produced a marked effect upon the topography of the islands and the shores of Thunder Bay (Fig. 125).

227. Mountains due to folding.—Nearly all the great mountain ranges of the world, including the Rockies, the

Fig. 125.—Thunder Cape and the Sleeping Giant, off Port Arthur

Andes, the Alps, and the Himalayas, are composed of strata that were originally low-lying or even submerged beneath the sea, but were uplifted as a result of the wrinkling and folding of the earth's crust. If one side of a thick pile of sheets of paper is placed against a wall, and pressure is exerted upon the opposite side, the folds and crumplings produced in the paper will represent what has taken place in the great earth sheets as a result of an enormous pressure exerted along one margin of an extensive area. This pressure is believed to be due to the crustal movements that arise from the settling and shrinking of the interior mass of the earth. The shrinking of the earth's crust has never yet been satisfactorily explained.

228. The features of rock folding.—We require no evidence of the folding of rocks other than that which is indelibly impressed upon the rocks themselves. The next three figures are pictures of actual rock strata. Figure 126 shows the trough-shaped fold which is known as the *syncline*. Figure 127 represents the inverted trough-shaped fold which is called the *anticline*. Frequently the folding is much complicated, and wrinkling confuses the

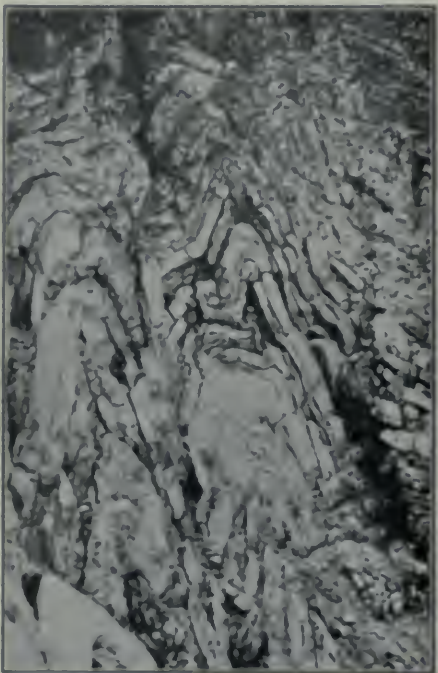
Courtesy of the Geological Survey, Canada

Fig. 126.—Syncline folds in Outer Range, south of Athabaska River

Courtesy of the Geological Survey, Canada

Fig. 127.—Anticline in Shumardia limestone, Lévis

general lines of fold. Figure 128 shows a system of wrinkling folds. Figure 129 is a diagram representing one of these complicated systems in which the strata have been made thin along the lines, *A A*, and thick at the curved portions, as though the rock components had been made plastic under pressure and had then been caused to flow into the regions of lesser pressure. These observations throw some light upon the changes that take place during the metamorphism of rocks (Sec. 113).



Courtesy of the Geological Survey, Canada
FIG. 128.—Drag folds in the Cougar quartzite, Selkirk Range

It frequently happens that, under the lateral pressure which produces folding, rocks are cleft along a plane, and one of the severed pieces is shifted along this plane of cleavage for a considerable distance. The Scottish mountain Ben Eay, which is about 3,300 feet high, bears unmistakable evidence of having been moved by such a thrust for a distance of ten miles (Fig. 130). Examples of thrust-faulting are also met within the Rocky Mountains just north of the Canadian boundary.

In consequence of the displacement of large masses of rocks through folding and faulting and by thrusts, the structure of mountains is frequently very complicated.

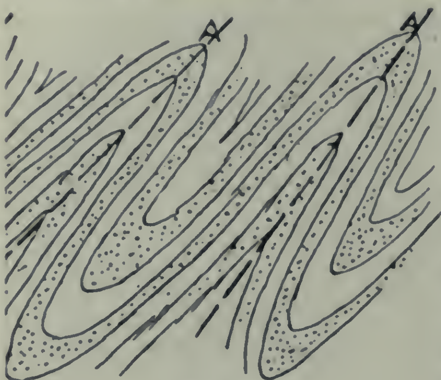


Fig. 129.

Sometimes the displacements cause the strata that were originally deeply buried to be elevated, so as to overlie strata that had been deposited above them. The complexity of mountain structure is still further increased by the unequal rates at which the rocks of different degrees of hardness are removed by weathering and erosion.

Fig. 130.—Ben Eay, Ross-shire, Scotland

229. Mountains due to faulting.—Frequently rock

masses fault along long lines, and the rupture is usually followed by a succession of depressions or elevations of one or both portions of the fractured rock. Changes such as these have taken place in various regions of the earth on such a gigantic scale as to produce lofty mountain ranges.

Noteworthy examples of mountains produced by faulting are the ranges that occupy the Great Basin of the western United States. When the Rocky Mountains were formed the Great Basin was elevated into a vast plateau in the form of an arch. Subsequent to its elevation a series of almost parallel fractures formed along the crown of the arch, and some segments of the shattered structure slowly settled. The segments that remained elevated constitute the numerous parallel ranges that rise from 3,000 to 5,000 feet above the

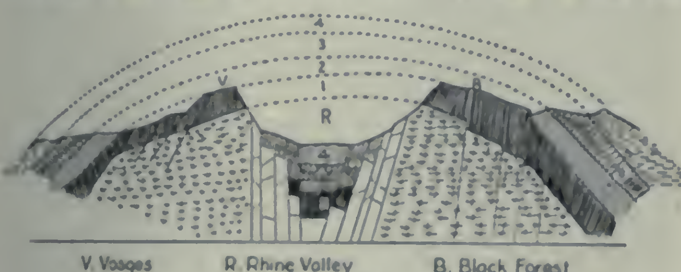


Fig. 131

subsided valleys. The faulting, in all probability, took place in a series of slow and gradual movements unaccompanied by violent earthquake convulsions.

The mountains that overlook the Dead Sea and the valley of the Jordan and the ranges bordering the valley of the Rhine are also examples of mountains produced by faulting (Fig. 131).

230. Origin and distribution of relict mountains.—Relict mountains are, as the name implies, remnants of

larger elevations. They have been carved out of plateaus by eroding agencies, such as running water, winds, and glaciers.

As a natural consequence of their mode of origin, mountains of this class usually exist either in isolation or in small groups. This scattered distribution is illustrated by the pyramidal mountains that have been produced by the erosion of the Sahara Desert plateau.

231. The characteristics of relict mountains.— The characteristic features of relict mountains have been determined, to a large extent, by the climatic conditions under which weathering and erosion took place, and in part by the differences in the rock strata. The pro-

Fig. 132.—View from the shoulder of Ben Nevis, looking south

cesses of desert weathering, namely, sudden and extreme temperature changes and wind erosion, have produced the sharp angles and hard, straight lines of the pyramidal mountains of the Sahara, while the flat "table" tops of

these mountains are due to horizontal layers of resistant rock which persist after the softer masses have been removed. Relict mountains that have been carved out in more humid lands have softer features in which curved lines predominate. This is illustrated by Ben Nevis, Scotland, the profile of which is shown in Figure 132.

Differences in the hardness of rock strata have given rise to some remarkable features of relict mountains. This is strikingly illustrated in the "bad lands" of the

Fig. 133.—A butte, Nebraska

semi-arid western United States. Conspicuous features in these areas are the toad-stool mounds and the monument-like structures known as *buttes* (Fig. 133). These are remnants of those rocks which, on account of their greater hardness, weathered more slowly than the surrounding masses. But even the hardest rocks of mountains and plateaus must eventually disappear, for these rocks, like other earth features, have a complete cycle of existence.

THE LIFE HISTORY OF MOUNTAINS

232. The period of elevation.—Previous to the middle of the eighteenth century, it was a matter of general belief that mountains are primitive and permanent earth features. But the study of the origin of mountains has shown us that this view is incorrect, for mountains have their periods of growth, maturity, and decay. We have plenty of evidence that the two latter periods are extremely long, and proof is not lacking that mountains are not built in a day. A study of the courses of rivers shows that the folding and faulting movements, by which the great ranges were formed, progressed gradually, and that only rarely did rapid, spasmodic movements take place. For example, during the periods of uplift

Courtesy of The Canada Publishing Co.
Fig. 134.—Gap of the Bow River near Banff, looking east

of the older ranges of mountain systems in various parts of the world, rivers, in many cases, established their channels at right angles to the direction of the ranges. At a later period new ranges were uplifted by folding or

faulting, and even in places where the axis of uplift lay directly across the course of the rivers, the waters were not deflected. It is obvious that the upheaval must have progressed so slowly that the river was able to cut its channel into the uprising strata faster than elevation took place. The Gap of Bow River (Fig. 134) illustrates this.

233. The weathering and denudation of mountains.—Mountains are exposed to conditions that promote comparatively rapid destruction by the agencies of weathering and denudation. The sparseness of vegetation and the rapid removal of detritus give the weathering agencies free access to the surface of mountains. Lofty peaks are especially exposed to disintegration by rapid and extreme changes in temperature, while the steep slopes give gravitation and stream and glacial action the most

Courtesy of the Geological Survey, Canada

FIG. 135.—Coast Range Mountains, showing rounded glaciated character

favourable opportunity for stripping off the materials as fast as they are loosened. In consequence of the rapid destruction by these agencies, the surfaces of mountains

are usually broken and rugged. The general features of the irregularities depend to a large degree upon the structure of the rocks. For example, the dome-like peaks (Fig. 135) of the Coast Range of British Columbia are produced by the glacial erosion of the softer strata overlying the intrusive rocks, while castellated peaks with towers and pinnacles and steep walls, such as those

Fig. 136.—Summit of Mount Tupper from Tupper Crest, showing castellated effects in jointed rock

of some portions of the Rockies (Fig. 136), are the result of the weathering of rocks of jointed structure.

234. Mature mountains.—The typical form of mountain valley is the *gorge;* but, as the mountains grow older, the gorges are cut wider, and broad valleys, containing wide stretches of agricultural land and having sloping rather than steep sides, are not uncommon among mountains that have reached maturity. The summits

of mountains that have reached this period in their life cycle are rounded, their surfaces have lost their rugged forms and hard lines, and the elevations melt into one another like sea waves (Fig. 132).

235. Mountains in old age.—In old age, erosion may have reduced mountains almost to plains. The low Laurentian plateau is an example of this. It contains only the basal portions of mountains that once towered several thousand feet above the sea that surrounded them. But the "tooth of time," by ceaseless gnawing through unnumbered years, has removed the lofty peaks and reduced the elevated plateaus to the low rounded knolls which are characteristic features of this area (Sec. 276).

236. Mountains and mining.—With the exception of a few materials, such as building stone, clay, and coal, the minerals of the world are limited to mountainous lands, and particularly to lands occupied by mountains that have been extensively denuded. The reason for this is, that while the economic minerals are widely disseminated throughout the earth's crust, it is only in regions where their particles have been gathered by some agency and confined in a limited space near the surface of the earth that they can be profitably obtained.

Among the substances that percolate through the strata of the earth and have power to dissolve mineral matters, the commonest are steam and water and fluid quartz. The solutions so formed escape from the interior of the earth through the cracks that are caused by mountain folding and settling. The minerals are deposited upon the walls of the cracks, or the quartz solidifies within them, and thus mineral veins are formed. Mineral veins are formed in other ways, but many containing valuable ores, such as those of copper, iron, silver, and gold, are produced in the way just described.

When mountains have been greatly denuded, the deeper and richer portions of the veins are exposed, and mining is thereby made easier.

The rich silver and gold veins of Cobalt and Porcupine were exposed upon the surface of the rocks by the extensive erosion of the ancient Laurentian Mountains. The silver veins of these districts were formed by deposits from water which escaped through cracks in the mountain strata, and the gold veins by intrusions of quartz that welled up into similar crevices.

The world's most remarkable and most valuable deposits of nickel are found at Sudbury, Ontario. These originated in the intrusion of a mass of molten rock, which formed a laccolith, having a volume of nearly 500 cubic miles. It was covered by a blanket of sedimentary rocks nearly 10,000 feet thick. Subsequent erosion removed the greater part of this covering, and the nickel deposits contained in the laccolith were made accessible.

TABLE

The relative heights of some of the highest peaks of the continents:

Mountain	Height	Range or Plateau	Continent
Everest.......	29,002 ft.	Himalayas	Asia
Kinchinjunga..	28,173 ft.	Himalayas	Asia
Aconcagua....	23,100 ft.	Andes	S. America
Chimborazo...	22,600 ft.	Andes	S. America
Kilimanjaro...	20,000 ft.	Interior Plateau	Africa
Mt. Erebus....	12,500 ft.		Antarctica
Elburz........	18,520 ft.	Caucasus	Europe
Blanc.........	15,775 ft.	Alps	Europe
Mt. McKinley.	20,500 ft.	Coast Mts.	N. America
Mt. Robson...	13,500 ft.	Canadian Rockies	N. America
Popocatepetl..	17,540 ft.	Mexican Plateau	N. America
Rainier.......	14,525 ft.	Cascade	N. America
Kosciusko.....	7,256 ft.	Eastern Plateau	Australia

CHAPTER XVIII

VOLCANOES

The Meaning of Volcano

237. The origin of the name. — The convulsive activities of volcanoes form a marked contrast to the slow and persistent processes of weathering, and are much more violent than the eruptions of geysers. The violent, fitful explosions of volcanoes fill modern man with awe, notwithstanding his scientific knowledge, and present to him not a few unsolved problems. Hence it is not surprising that the ancient Greeks saw, in the changing flares of the mountain of the Lipari Islands, the forge of mythical Vulcan, to whose name we are indebted for the word volcano.

238. The matter ejected by volcanoes.—Some of the names given to the materials ejected from volcanoes are relics of the erroneous belief that a volcano is a burning mountain. The materials contained in a volcano are not burning, for there is no alteration of matter, such as takes place during the combustion of wood, or gas, or coal. The volcanic material that is called *ash* is not the ash left when substances are burned, but is a grayish powder which is produced from rock materials by explosions that shatter them into small particles. The flares, such as those which appear to burst forth from Stromboli at intervals of twenty minutes and which have won for that volcano the title "Lighthouse of the Mediterranean," are not flames. They are reflections from the clouds of steam which float above the volcano, and which

are lighted by the glowing lava welling up within the crater. These lights resemble the reflections of the electric illuminations upon the cloudy sky overlying a city.

In the next place, a volcano is not necessarily a mountain. It is true that a mountain is usually built by the accumulation of the ejected matter, but the mountain is only secondary and is rarely present in the early stages of the volcano. The essential features of a volcano are the issuance of gases and the ejection of rock materials from a vent. The vent is the exit of a tube leading from a reservoir of volcanic matter, situated somewhere within the earth. Vents are usually located on great cracks in

Courtesy of Henry Holt & Company

Fig. 137.—Ropy surface of flowing lava, Mauna Loa, Hawaii

the earth's crust and may occur on plains as well as among mountains. For instance, a fissure appeared in a plain in Mexico at a distance of nearly forty miles from any mountain, and through it was ejected in a single night,

sufficient volcanic material to build up the mountain of Torull.

The materials that issue from volcanoes may be either solid, liquid, or gaseous; and the relative quantities of these three forms vary with different volcanoes, and, in some instances, during different eruptions of a single volcano.

Lava, or molten rock (Fig. 137), is the most important of all volcanic products, for it forms the most extensive masses and fields of volcanic matter, and is the principal material from which all the solids that issue from volcanoes are formed. Among these solids are volcanic ash, volcanic dust, and scoria. Volcanic dust is produced by gas explosions, which shatter the lava into a brownish powder with particles so small that they can pass through the meshes of the finest silk. These particles sometimes float in the air for months. Volcanic ash originates in the same way as volcanic dust, but its particles are much coarser, and, consequently, they do not float so long in the air. Scoria is a material resembling slag from a foundry, or cinders from a furnace. It is solidified lava that contains many bubble cavities, formed by the escape of steam and other gases when the lava was solidifying. When the bubble cavities are extremely numerous, the scoria is light enough to float on water and is then known as pumice-stone.

The most abundant of the gases that escape from volcanoes is steam. The quantity of water necessary for the formation of this steam is usually very great, and in the case of eruptions of the most extensive type, it is enormous. For instance, the vapour ejected from Mount Etna during an eruption that lasted for one hundred days, was computed to be the product from 70,000,000 cubic feet of water—an amount sufficient to form a lake a mile long, a quarter of a mile wide, and

more than ten feet deep. These great volumes of steam condense above the volcano to form rain-clouds, which are charged with electricity and give rise to violent thunder-storms, with heavy downpours of rain. The rain, falling upon the freshly ejected dust and ash, converts them into soft mud, which runs down the inclines. These mud streams have been known to bury villages and even cities. Such was the fate of Herculaneum, Italy, during the eruption of Vesuvius in the year 79 A.D. In addition to water vapour, the most common volcanic gases are carbon dioxide, sulphur dioxide, hydrogen, hydrochloric acid, and oxygen.

As already stated, the volcano builds its own mountain from the lava that flows from the vent, or from the lava and other materials which are expelled with explosive force. When a volcano is sending forth volcanic matter, either in the form of a steady stream of lava, or as matter that is ejected with explosive force, the volcano is said to be in *eruption*. Sometimes explosive eruptions are of great violence. To cite an instance, during an eruption of Cotopaxi in South America a mass of rock weighing two hundred tons was hurled to a distance of nine miles, while heavy showers of dust, so fine that ten millions of the particles weighed only one ounce, fell sixty-five miles away.

The Structure and Composition of Volcanic Cones

239. Lava cones.—The differences in the volcanic materials give rise to variations in the form and the composition of volcanic cones. Some are composed almost wholly of lava that rises from the vent and overflows around its margin, to form, at first, a ring, and afterwards, as the accumulations from the overflow raise the mass higher and higher, to form a cone. Some varieties of

lava remain fluid for a considerable length of time. This permits of their spreading over a larger area, and thus a cone of very gradual slope is built (Fig. 138). Other lavas have the consistency of a mass of thick paste and build up dome-shaped cones with steep inclines.

Courtesy of Henry Holt & Company

Fig. 138.—Fujiyama, a volcanic cone in Japan

240. Cinder and ash cones.—Some volcanic cones are built up almost entirely from the fragments of rock materials that are thrown into the air during eruptions; these are called *ash* or *cinder* cones. Naturally the accumulation is greatest immediately around the vent, and gradually decreases outwards. The loose materials piled near the vent roll down the slope until they find a position of rest, and thus build up an almost perfect cone, having steep sides with a more or less concave profile.

241. Composite cones.—The largest volcanoes usually build up cones that are composed of mixed deposits of

lava and ashes; these are known as *composite cones.* In the early stages of their growth their form is conical; but as the streams of lava flow out unevenly, it gradually becomes more and more irregular. This is particularly

Courtesy of Henry Holt & Company
Fig. 139.—Cinder cone forming the summit of Mount Vesuvius

the case when the cone has become so high that the pressure of the lava column within the tube causes vents to burst through the sides of the hill. From these vents lava streams issue, and around them new cones, called *parasite cones,* are frequently developed. Upon the surface of Mount Etna more than two hundred parasite cones can be seen. In some cases the original vent ceases to discharge and becomes plugged with solidified lava.

242. The crater and volcanic chimney.—The upper portion of the tube through which the volcanic materials rise from the interior of the earth's crust is called the *crater.* It is generally funnel-shaped and may become

filled, for short intervals, with ash and cinders that fall within it during an eruption. Usually the tube becomes lined with a hollow cylinder of solidified lava called the *chimney*. The bore of the chimney varies during the life of the volcano. At times the column of lava that rises within the chimney is sufficiently hot to melt the inner walls, thus enlarging the bore. At other times it becomes so cool that some of it solidifies upon the inner surface, and so lessens the bore. When the volcano becomes extinct, a plug of lava solidifies within the chimney. This plug, being of very hard rock, sometimes remains as a prominence, in an ancient volcanic area, after the softer portions of the volcanoes and neighbouring mountains have been removed by erosion. A good illustration of this formation is furnished by Mount Johnson, situated twenty-two miles south-east of Montreal. It rises from a level plain to a height of nearly seven hundred feet (Fig. 99).

Representative Volcanoes

243. Kilauea.—Before undertaking a study of the causes underlying volcanic phenomena, it will be helpful, as a preparation for that study, to become familiar with the behaviour of a few typical volcanoes. Kilauea, one of the most remarkable of volcanoes, is situated on an island of the Hawaiian group. The crater is in the form of an elliptical bowl nearly seven miles in circumference. The inner surface of the walls of the crater is terraced with deposits of hardened lava, while the centre of the floor is occupied by a lake of lava, the surface of which is usually at dull red heat, with jets of lava at white heat frequently bursting through it. The level of this lava pool is constantly changing. It rises when underground channels that lead from the chimney become stopped up, and sinks when the lava melts the rocks that

obstructed these channels. In 1840 a stream of lava issued from one of these tunnels in the side of the mountain eleven miles from the crater, and flowed down the slope a distance of eleven miles into the sea. This lava stream soon cooled and congealed on the outside, but remained molten within, thus forming a continuation of the tunnel. The hot molten lava pouring from this tunnel into the sea produced enormous clouds of steam, while the lava was shivered into tiny particles that were thrown into the air in clouds that darkened the sky.

244. Mount Pelée.—In the island of Martinique, one of the West Indian group, is situated the volcano known as Mount Pelée (Fig. 140), which in May, 1902, furnished an unparalleled example of the rapidity with which a volcano can belch forth destruction. From a gash that had formed in the rim of the crater, a blast of steam, mixed with sulphur dioxide, dust, and ash, swept down upon the town of St. Pierre with a speed of nearly one hundred miles an hour. Trees and buildings were hurled from the path of the rushing blast, and its intense heat of 1,400°F. destroyed every

Courtesy of Henry Holt & Company
Fig. 140.—Spine of Mount Pelée

form of life. All the inhabitants of the town, with a single exception, were instantly killed by the hot steam and poisonous gases. Following this eruption there were others, during which steam and ash were projected vertically upward to a height of nearly seven miles.

245. Krakatoa.—In August, 1883, Krakatoa, a small island in the Strait of Sunda, was almost wholly destroyed by a series of terrific volcanic disturbances extending over several days and culminating in the most violent explosion the world has ever experienced. More than one cubic mile of rock was instantly shattered into fragments. The report of this explosion was heard in Australia, two thousand miles away, and the violence of the concussion was such that the walls of buildings in Batavia, one hundred miles distant, were cracked. Sea oscillations were created that were distinctly felt in South America, and a sea wave, more than one hundred feet in height, swept over the neighbouring coasts, overwhelming towns and hurling ocean steamships high upon the shores. The rock fragments were thrown so high that the finer particles were caught by the upper currents of air and carried all around the world. For months these gave to the sunsets of places as far distant as northern Europe and western America a peculiar reddish glow.

The Theory of Volcanic Action

246. Factors.—In explaining the action of volcanoes, three things must be accounted for:

(1) The presence of molten rock

(2) The cause of the explosive eruption

(3) The source of the enormous quantity of steam.

247. The origin of heat and molten rock. — We know that the interior of the earth is highly heated. This heat has been retained by the thick non-conducting blanket of rock on the surface of the earth. In the case

of the volcano, we may add another source of heat, namely, friction; for volcanoes occur where earth upheavals, with folding and faulting, are taking place most rapidly. The heat from these sources will suffice to fuse all rocks that produce lava, provided the pressure is sufficiently reduced. The arching of hard resistant rocks under the strains and pressure due to folding, relieves the pressure upon the rocks underlying them to such an extent that the latter fuse under the intense heat. Since a mass of molten rock occupies a greater space than an equal mass of solid rock, expansion due to fusion forces the lava to seek an outlet along the line of least resistance. The pressure of expanding gases, and the squeezing force exerted by the rock walls of the reservoir, as they respond to the movements of folding and faulting, also tend to move the lava. Intermingled with the lava are great volumes of superheated water, and this water has a direct action in causing the explosion.

248. The cause of the explosion.—As the lava moves upward, it carries with it the imprisoned water, which is prevented from turning into steam by the enormous pressure of the lava above it. As the lava and the water rise, the pressure is rapidly diminished. Presently a point is reached where the pressure is no longer sufficient to prevent the formation of steam, and this takes place with a powerful explosive force. Each particle of water, suddenly converted into steam, contributes its share toward hurling the lava from the crater and shattering it into minute fragments.

249. The source of water in volcanoes.—The problem of the source of the enormous volumes of water that are required to yield the steam that issues from volcanoes has not been solved to the satisfaction of all geographers. It is probable that surface water, which percolates through the superficial strata or which pours through fissures in

the earth's crust, plays some part in volcanic action, by penetrating the region of hot rock, where it is converted into steam. The fact that many volcanoes, such as Etna, Kilauea, and Vesuvius, are in eruption more frequently during rainy seasons than in times of drought, supports the view that this surface water sets into operation other forces that had previously been ready to act. The theory that volcanic water is derived from that which was imprisoned within the earth's strata when these were laid down, is advanced by some geologists, while those who adhere to the planetesimal hypothesis claim that great quantities of water were held upon the surfaces of the bodies that were combined in forming the interior of the earth (Sec. 323).

Active, Dormant, and Extinct Volcanoes

250. Distinction.—Almost all volcanoes have periods of eruption and are then described as *active.* The periods of activity are followed by periods of rest. When the period of rest extends through a number of years, and in the meantime ebullition is heard within the crater and steam arises, the volcano is described as *dormant.* When all expressions of volcanic energy, including the discharge of steam, cease, it is customary to regard the volcano as *extinct.* We cannot, however, distinguish with any degree of certainty an extinct from a dormant condition. Vesuvius, prior to the devastating eruption of 79 A.D., by which Herculaneum and Pompeii were destroyed, had been considered extinct. No eruptions had taken place for centuries, and forests were growing within its crater.

251. The extinct volcanoes of Canada.—There are no active volcanoes in Canada, but there are many extinct volcanoes, although none of these is of great size. Some of the conical mountain peaks of the western

cordillera were built up by volcanic action in quite recent geological ages. Mount Baker, Washington, close to the Canadian border, has probably been in eruption at a period later than the Ice Age, and beds of volcanic ash of quite recent date have been traced, covering large areas of the Yukon.

The interior plateau of British Columbia contains the eroded and much reduced remnants of numerous volcanoes of earlier geological periods. Farther west, both in the plateau area and in the Coast Range, intrusions of lava between the strata of older rock formations occur on a scale unequalled elsewhere in the world. These *batholiths*, as the intrusions are called, extend through British Columbia and Alaska for a distance of more than 900 miles and over an area having an average width of 100 miles. The overlying strata have been bowed up, or faulted, by the intrusions, and the lava has burst through the fault fissures and spread over the original surface, sending its streams in every possible direction, and thus producing a most complicated rock structure. Since these formations descend to great depths, the name batholiths (Gk. *Bathos*, deep) is appropriate. The Canadian Shield contains the stumps of many volcanoes extinct for ages and now worn to low, rounded knobs. Mount Royal, at Montreal, is the most westerly member of a series of extinct volcanoes that rise from a level plain to heights of from seven hundred to sixteen hundred feet. Mount Johnson, described in Section 242, is another member of this range.

Fissure Eruptions

252. The meaning of fissure eruption.—Though volcanic vents are usually small openings that lead from fissures which are located deep within the earth's crust, many instances are found of volcanic matter having

been poured from the entire length of fissures that extended for many miles across the surface of the earth. The geological history of Scotland shows that a large portion of the north of that country had its birth in an eruption of this kind, and that the fissure probably extended to Iceland, which owes its origin to the same source. What appears to be a remnant of this fissure exists in the latter island to this day, in the form of a cleft 600 feet deep and nearly sixty miles long. On this cleft are several volcanic vents, the largest of which is Skaptara, one of the world's most remarkable volcanoes. In 1783 it poured out a tide of lava such as has probably never been equalled by that of any other volcanic eruption.

Fig. 141.—Columnar basalt, Fife, Scotland

The plateau area of the Columbia Valley in British Columbia and of the States of Washington, Oregon, and California, forming a tract of nearly 200,000 square miles, was built up by a series of eruptions from fissures. The

batholiths of western British Columbia and the Yukon are also largely of fissure origin.

253. The decomposition of volcanic rocks.—Many varieties of lava decompose rapidly under the action of weathering agencies. The rich wheat lands of Oregon and Northern California are the product of the decomposition of the volcanic rocks of which the plateau was originally formed.

When the softer portions of volcanic rocks have been removed by weathering, peculiar formations frequently remain. These are composed of the harder materials. Mount Johnson has already been described as an example of a volcanic plug. The Palisades along the Hudson River are remains of fissure products. Their structure represents a system of jointing that occurs when lava from fissure eruptions solidifies. The most perfect forms of this system of jointing are hexagonal columns (Fig. 141). These also compose the walls of Fingal's Cave in Scotland, and constitute the Giant's Causeway in Ireland.

The Volcanic Belts

254. The two great volcanic belts.—With few exceptions, the active volcanoes of the earth are arranged in two great belts (Fig. 142). One of these borders the Pacific Ocean, and contains the volcanoes of the cordilleras of South America and North America, those of Victoria Land, those of the Aleutian Isles, and those of the islands of Japan, Malaysia, and New Zealand. The other belt borders the Mediterranean and is projected eastward along the continental axis of Asia and westward across the Atlantic, where it includes the volcanic islands of the Caribbean Sea. In Mexico it crosses the belt that was first described, and its Pacific

extension contains the volcanoes of the Hawaiian and other tropical islands.

Fig. 142.—Volcanic belts

255. The underlying cause of these belts.—These belts correspond to the zones where the great crustal movements of the earth are now taking place. In earlier ages there were volcanic belts in existence along the unstable sea margins of those times. Many of the volcanoes of these ancient belts are now extinct. The situation of these belts indicates that volcanic phenomena are directly connected with crustal movements.

CHAPTER XIX

EARTHQUAKES

General Characteristics

256. The number of earthquakes.—Earthquakes have done more than even volcanoes to shatter man's faith in the stability of the earth. The comparison "Firm as the hills" becomes idle words when we are confronted with the reports of the seismographer, which show an average of nearly thirty thousand earthquakes a year. By far the greater number of these are slight tremors, unperceived by the senses, but recorded by the seismograph.

257. The use of the seismograph.—The seismograph is an instrument which has been devised for detecting earthquake waves and testing their violence. By observations taken at two or three different places, the location of the earthquake can be accurately determined.

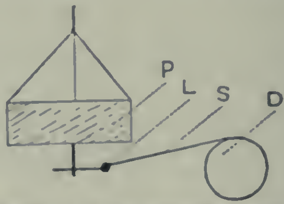


Fig. 142 (*a*).—Seismograph. *P.* Heavy pendulum, so suspended that it does not vibrate when there are earth tremors. *D.* Revolving drum which vibrates with earth tremors. *S.* Style which traces the vibrations. *L.* Magnifying levers.

This was illustrated at the time of the Yakutat Harbour earthquake in 1899. So isolated is this part of the coast that scientists received no report of the event until several weeks after its occurrence. In the meantime seismographers located the earthquake centre with precision, and made a fairly accurate estimate of its effect.

258. Earthquakes distinguished from surface tremors.—Earth tremors are frequently caused by surface commotions, such as the jarring of a heavy wagon upon a rough road, the passing of a railway train, the falling of the water of a cataract, the concussion of a rock blast, etc. These tremors resemble those of earthquakes, and are sometimes called minor earthquakes, but strictly speaking, a tremor of the earth is not an earthquake unless it is caused by some force that acts suddenly at a point below the surface of the earth. The effect is to cause a shaking of the earth's crust immediately over the point of disturbance or along a certain level extending from that point. Earthquakes are of varying degrees of intensity, ranging from those that can be detected only with the seismograph to those that are of sufficient violence to topple down the strongest buildings. Those that have been of this destructive nature, though greatly in the minority, have taken large toll of human life, and have considerably modified the surface features of limited areas.

Typical Earthquakes

259. The Lisbon earthquake of 1755.—On November 1st, 1755, there occurred at Lisbon one of the most appalling earthquake disasters in the world's history. It was preceded by a loud rumbling report like the explosion of a gigantic powder blast. This sound had scarcely ceased when the earth began to rock and to heave upward with such violence that, within a few minutes, the buildings throughout the greater part of the city were thrown down. The people near the seashore rushed toward it to escape from the falling walls. There they saw the waters at first draw away from the land and then return in a huge wave that overwhelmed all who had taken refuge on the wharfs. At almost the

same instant a great rift in the earth swallowed up the wharfs, and these remained buried beneath 600 feet of water. Within the space of half an hour, sixty thousand people perished in this disaster.

260. The San Francisco earthquake of 1906.—The earthquake that brought about the destruction of the greater part of the city of San Francisco was less disastrous to human life than the Lisbon earthquake, but it presented some instructive illustrations of earthquake phenomena. Those who were active observers of this convulsion describe the earth as rocking to and fro, and as having, at the same time, a movement up and down, so that it was impossible to stand or to walk. The walls of many of the stronger buildings were cracked, while the weaker structures were thrown from their foundations (Fig. 143). Evidence of the cause of this disaster remained in the form of a great fault four hundred miles in length, with a horizontal shifting along one side of the fissure, varying from three to twenty-one feet. The vertical displacement was also variable, but at no point was there an uplift of more than four feet. This cleft passed close to the western borders of the city. The

Courtesy of U.S. Geological Survey
Fig. 143.—Buildings wrecked by the San Francisco earthquake

earthquake shocks were due to the vibrations set up by the sudden movement of enormous masses of the earth's crust directly below the fissure, which was only the surface manifestation of the more deeply seated movement.

261. The Yakutat Bay earthquake of 1899.—For twenty-seven successive days during the month of September, 1899, the coast of Alaska was rocked by a series of earthquake shocks. Among these were several that shook at least a quarter of a million square miles of land so violently that the tremors were felt around the

Courtesy of the Geological Survey, Canada

Fig. 144.—Fault with throw of 4½ feet, Yakutat, Alaska

world. Since the most violent disturbances occurred in an almost uninhabited region, there was probably no loss of life, but seven prospectors, who were encamped close to an old fault line in an area that was almost in

the centre of the disturbances, had a miraculous escape. The whole shore-line was deformed by movements of rocks. In some places masses were depressed several feet along old fault planes, while in others the broken strata were uplifted from two to forty-seven feet (Fig. 144). The mountain sides were tilted at various angles, shattering glaciers and precipitating avalanches of snow and ice. Following one of the most violent disturbances, a huge wave rolled through the bay and overwhelmed stretches of forest fifty feet above sea-level.

The Theory of Earthquakes

262. Tectonic earthquakes.—A study of the phenomena presented by many earthquakes such as those described in the preceding sections, has led to the conclusion, now almost universally accepted, that violent and destructive earthquakes are caused by the faulting of large masses of the earth's crust along great fractures. All the three earthquakes described above present examples of extensive rifts in the earth's surface. The fracturing and faulting are the results of the strain to which the strata are subjected in consequence of the shrinkage that takes place in the interior of the earth. To accommodate themselves to the changes in volume, the strata become crumpled and folded, and, when the strain of folding becomes greater than the rocks can bear, they break, and one or both sides of the fracture shoot upward or downward. The concussion caused by the sudden movement produces loud reports and rocking of the earth's crust. Earthquakes that originate in this way are called *tectonic earthquakes* (Greek—*tectonikos*, pertaining to building).

263. Volcanic earthquakes.—Records of volcanic activities show that in nearly all instances earthquake shocks of greater or less magnitude precede the eruptions.

These shocks are probably caused by the rapid movement of enormous masses of lava into subterranean cavities. The concussion of these masses against the containing rock walls resembles that of heavy waves dashing into sea caves, and causes the walls to quiver. Earthquakes caused in this way are called *volcanic earthquakes*. These are usually less violent than tectonic earthquakes and are limited to smaller areas of operation.

264. Earthquake waves.—To understand the irregular to-and-fro, up-and-down movements of the land that are characteristic of earthquake waves, we must remember that solid rocks are elastic and will bound and rebound after concussion, just as a pebble does when dashed forcibly upon a hard pavement. The shock caused by the sudden displacement of a large mass of matter sets the elastic rocks vibrating, and the vibrations travel outward in all directions from the centre of shock, comparable to water ripples spreading from a point where a pebble is dropped into a pond. And just as water ripples are reflected from the margins of a pond and from floating logs or pieces of ice until the ripple system becomes very complex and irregular, so the earthquake waves become extremely complex when they encounter obstacles such as strata with different degrees of elasticity or formations placed at various angles to the line of progress, and when they meet with reflected waves. This produces irregular jarring movements, such as those that were experienced during the earthquake at San Francisco in 1906.

265. The velocity of earthquake waves.—Earthquake waves may travel far from the shock centre. In many cases they pass completely around the world. The wave diminishes in intensity as the distance from its point of origin increases. Earthquake waves move around

the earth at the rate of nearly two miles a second, but their velocity through the earth, that is along the line of the earth's diameter, is much greater, being more than six miles per second.

266. Succession of shocks.—The complexity of the earthquake wave is sufficiently great to account for the duration of the shock through several seconds or even minutes. A succession of shocks extending over a period of many days, as in the case of the Yakutat Bay series, is explained by the fact that there is a succession of crustal movements and displacements, accompanied by grinding and tearing as the edges of the fault planes move one against the other.

267. Surface changes caused by earthquakes.—Although earthquakes have caused several of the most appalling disasters that have visited mankind, they have made comparatively little impression upon the geographical features of the earth.

Here and there are to be found fault lines that have so weakened the crust as to permit streams to begin their work of erosion.

Occasionally, earthquakes have been accompanied by the settling of considerable areas of the earth's crust, and the depression has become the bed of a lake. An instance of this occurred in the Mississippi Valley during the earthquakes of 1811-1813, when large areas were depressed, and are now covered with water in which the original forests are still standing.

Rivers have been drained into earthquake fissures, and springs have been obliterated, or new ones have been formed. Temporary spouting springs have been produced by the pressure of the moving strata forcing large quantities of sand and water to spurt out. The expelled sand, by collecting around the outlets, has built up sand cones, with crater-like depressions in their summits.

Earthquake Belts

268. Earthquake belts are coincident with volcanic belts.—There are two earthquake belts, and these are coincident with the two volcanic belts (Fig. 142). In the belt around the Pacific Ocean, approximately fifty-seven per cent of all recorded earthquakes have occurred. In the other belt, which borders the Mediterranean and Caribbean Seas and extends across the Atlantic and Pacific Oceans, nearly forty-one per cent of all recent earthquakes have had their centres. Nearly all *sea-quakes*, that is, sea movements that indicate submarine earthquakes, occur in this belt.

Earthquakes in Canada

269. Canada is relatively free from earthquakes.—Many people living in Ontario have experienced the sensations of mild earthquake shocks, such as rumbling sounds and earth tremors which shake the walls or cause dishes to rattle, but seldom have any shocks more violent than these disturbed eastern Canada. A few, however, of sufficient violence to attract the attention of the historians, have occurred within historic times. Noteworthy among these is the one recorded by the Jesuit priests in 1663. The shocks were most violent in the St. Lawrence Valley, but were felt as far away as Boston. In eastern Ontario the ground rocked, and the trees, with their branches interlocked, swayed back and forth until their tops almost touched the ground. The Indians, astonished at these strange movements, declared that the trees were drunk.

CHAPTER XX

PLAINS AND PLATEAUS

General Description

270. The general characteristics of plains. — The common definition, "A plain is a level area of low-lying land," while expressing the type features of plains, falls far short of conveying a conception of the numerous varieties of areas that are included under the term. When it is said that plains are level, the meaning is that they lack the broken and rugged physical features of mountains. But plains have many degrees of levelness, varying from the monotonous flatness of such plains as those of Manitoba and Saskatchewan (Fig. 145) to the

Courtesy of the Canadian Pacific Railway

Fig. 145.—A level plain, Saskatchewan

undulating diversity of those of which eastern Alberta and southern Ontario are types. The latter have only small portions that are actually level, but they are

devoid of mountainous irregularities (Fig. 146). Plains are low-lying in the sense that they do not rise conspicuously above their surroundings.

Courtesy of Interprovincial Airways, Ltd.

Fig. 146.—Aeroplane view of undulating plain

271. The general characteristics of plateaus.—It is customary to define a plateau as an area that rises to a conspicuous height and presents a considerable extent of level surface. Here again a brief definition fails to express the many variations of meaning that are associated with a comprehensive geographic term. For example, that portion of the Province of British Columbia which lies between the Coast Range and the interior ranges is part of a plateau which has a length of more than two thousand miles with an average width of one hundred and fifty miles. It is called a plateau, because its mean altitude is nearly three thousand feet, and because its surface, though diversified with deep valleys and rolling hills, is, in general, of the character of an undulating plain (Fig. 147). On the other hand, although the central plain of the United States rises gradually west

of the Mississippi until it reaches an altitude of five thousand feet, it is not described as a plateau, but is regarded as a part of the Great Central Plain. The gradual ascent and the fact that the plain is overshadowed by the Rocky Mountains, which form its western boundary, detract from the impressiveness of its character as a plateau.

Courtesy of the Geological Survey, Canada
Fig. 147.—A plateau, British Columbia

In contrast with the last example, the Appalachian area, which lies along the eastern margin of the Great Central Plain, is called the Appalachian Plateau, although it rises to a height of only one thousand feet. In this case its character as a plateau is accentuated by the fact that it towers conspicuously above the adjoining plain.

Origin of Plains

272. Marine plains. — The ocean shores of many countries consist of plains that have originated in various ways. In a preceding chapter we learned that sediment

carried by rivers, ocean waves, glaciers, and other agencies, is deposited upon the bed of the sea along the margins of the continents. Owing to the constant movement of the water, any depressions in the ocean floor are filled with these deposits. Subsequent elevation of this floor above the level of the sea results in the exposure of a plain, with its seaward edge sloping below the water.

The eastern coast of the United States, from New York southward to Florida is a fairly continuous plain, varying in width from sixty to one hundred miles. It originated in the way just described.

The plain extending eastward from Perth to Montreal, and southward past Lake Champlain, contains fossils of marine forms and bears other evidences that it was formed in a similar way along the shores of a sea which gradually receded owing to the elevation of the land at the close of the glacial age.

Barrier beaches, bars across harbours, and salt-marshes, are all examples of marine plains. For descriptions of the origin of these see Sections 213, 212, 214.

273. River plains.—Great areas of all the continents consist of plains that are in large measure due to sedimentary deposits from rivers. Rivers are not only important eroding agents themselves, but they are also the carriers and distributors of the detritus produced on the uplands of the continents by weathering and other eroding agencies. In consequence of this disposal of materials, we have in Asia the great plains of the Hwang Ho, the Ganges, and the Euphrates; in North America the plains toward the mouth of the Mackenzie and of the Mississippi; and in each of the other continents areas of very considerable extent, which originated from sediment carried by rivers.

River deltas and alluvial fans (Secs. 165, 166) are examples of plains that have been formed from sediment

carried from the highlands by streams. In these cases the deposition takes place over a somewhat limited area, as a result of the sudden check given to the velocity of the currents. In delta formation this check is due to contact with the waters of the sea or of a lake; and in alluvial fan development it is caused by a stream from a steep slope spreading out upon the surface of a level plain.

274. Drift plains.—Glaciers have played an important part in the formation of plains on nearly all continents,

Courtesy of the Geological Survey, Canada
Fig. 148.—Morainic topography, near Aurora, Ontario

and particularly in Europe and North America. During the ice age glacial drift, consisting of rock flour and other material torn from the strata over which the glaciers passed, was spread out over a large portion of southern Canada and a considerable area of the northern United

States. This drift extended in the west down to the valley of the Missouri River, and in the east into the state of New Jersey. The drift obliterated, in large measure, the inequalities of the rocks over which it was strewn and converted the area into a great drift plain. Only here and there throughout the southern part of Ontario, as at Collingwood, Hamilton, and a few other places, do ridges of the almost buried rocks rise above its surface. The plain-like monotony is further relieved by shallow valleys which have been cut by streams, and also by lines of morainic hills that rise from fifty to two hundred feet above the general level (Fig. 148). These hills are interspersed with small lakes or with marshes and swamps, which have been produced by the filling up of small lake beds with sediment and decayed matter. The soil of this drift plain, since it is derived from almost every kind of rock, is unsurpassed in the variety of its mineral components, which furnish an almost inexhaustible supply of inorganic plant foods.

275. Lake plains.—These plains, as their name implies, occupy the beds of lakes. Some of these were gradually filled with sediment from rain wash and rivers, together with the remains of plants that once grew around the margins and in the shallow waters. Their growth has been gradual—the lakes slowly changing to marshes, the marshes to swamps, and, finally, the swamps to dry land. Numerous examples of these transitional stages may be seen in all parts of Ontario.

Among the world's most noteworthy lake plains are the Red River Valley and that part of Northern Ontario that is known as the "Clay Belt."

The eastern prairie steppe, of which the Red River Valley forms the greater part, is the site of a glacial lake known to geologists as Lake Agassiz. This was a body of fresh water whose area was greater than the combined

areas of the present Great Lakes. It became partly filled with silt, carried into it by the waters of the retreating glaciers, and with the remains of aquatic and shore plants. The melting of the glaciers opened drainage channels to the north, and the water drained away, with the exception of that in a few depressions, such as the site of the present Lake Winnipeg. Thus there were brought into existence the very level and extremely fertile lands of Dakota, Minnesota, and southern Manitoba.

The Clay Belt of Northern Ontario is a vast area composed largely of stratified clay and sand. One line of the Canadian National Railways runs through it from east to west for more than five hundred miles. It occupies the site of a great lake which Professor A. P. Coleman has named Lake Ojibway. This lake had a history similar to that of Lake Agassiz, for it was formed by the damming back of the waters of the melting glacier as it retreated northward. The lake at one time occupied an area of nearly 50,000 square miles, and its south-eastern portion extended even across the Height of Land into the Ottawa basin in north-western Quebec. Sediment was carried into it by glacial and other streams; and this, mingled with the vegetable matter produced by plant decay, constitutes the remarkably fertile soil of this great plain. While the surface of the lake deposits is in general very level, it is intersected by numerous ridges of Laurentian rocks and moraines of glacial drift.

276. Plains of erosion.—In the chapter on weathering and erosion, and in that on rivers, we learned that many agencies are at work reducing mountains, broadening valleys, and lowering divides; in brief, these forces are engaged in converting hills and mountains into plains. The changes take place very slowly, and long periods are required to produce noticeable results, but some

extensive plains have been produced in this way. A surface reduced by erosion almost to base level, so that most of it is approximately plain, is called a *peneplain* (almost plain) (Fig. 149). The Canadian Shield is a good example of a peneplain formed by the erosion of an ancient mountain system. These mountains belonged to early geological ages, and have been reduced, with the exception of that portion which constitutes the mountains of Labrador, to a comparatively low, undulating area of knolls, with an occasional higher peak —the remnant of a mountain mass that was composed

Courtesy of the Geological Survey, Canada
Fig. 149.—Laurentian peneplain, near Campbellford, Ontario

of more resistant rock than its neighbours. The altitude of this peneplain, at its highest part, is only about 1,600 feet, or about the same as that of the plains of Saskatchewan. The valley of the Rhine and the larger portion of the New England States are other examples of plains which originated in the erosion of ancient highlands. An intermediate state is illustrated by the round-shouldered "Bens" of the Scottish Highlands.

These mountains, seldom more than 3,000 feet high, are the stumps of the ancient and much loftier Caledonian Range, which is now reduced almost to a plateau.

Origin of Plateaus

277. Plateaus due to crustal movements.—We have learned in preceding pages that the surface of the solid earth is not stable. The Temple of Serapis (Sec. 198) sank below the level of the sea and then rose again, and similar changes have taken place in other parts of the world. We have already studied the horizontal thrusts that give rise to mountain folds; but, in addition to

Courtesy of the Geological Survey, Canada

Fig. 150.—Gulch in a Yukon plateau. Hydraulicing for gold in progress

these, there are vertical movements that cause elevation or depression of large areas of the earth's crust, without throwing the strata into folds. One of the effects of movements of the latter class is to elevate large portions of the earth's crust to such heights, or into such conspicuous relief against surrounding areas that they are recognized as plateaus. The giant plateau of the Yukon Territory made famous by the Klondike gold fields, was

produced in a relatively recent geological period by the uplifting of a peneplain (Fig. 150). Subsequent to its elevation the surface has been deeply trenched by rivers, the erosive powers of which were much increased by the greater height of the area.

278. Plateaus of accumulation.—The origin of some plateaus is ascribed to the accumulation of deposits on the surfaces of former plains or mountain valleys. The plateau of the Columbia River is a noteworthy example. Here, over an area of 200,000 square miles in Washington, Idaho, and Oregon, is a series of lava sheets overlying one another to a depth, in places, of more than 4,000 feet. This plateau arose upon a mountain area, from the successive outpourings of molten rock through fissures in the earth's crust. The earliest floods filled the valleys; the later floods submerged the summits of the mountains. The plateau of Iceland and that of the Deccan of India also originated in accumulations of lava.

Greenland and Antarctica are ice plateaus that have been built up by the gradual increase in the thickness of the ice sheets that cover the land. As far as has been determined, the land consists for the most part of broad and comparatively low valleys, interspersed with mountain ridges. The ice-cap that covers nearly all Greenland, with the exception of a narrow fringe of coast-line, has, in the interior of the island, a thickness of four to five thousand feet. The ice-field of the plateau of Antarctica is estimated to be at least 10,000 feet thick.

The Erosion of Plains and Plateaus

279. The relief of plains.—Since plains are usually low-lying and comparatively level, their features of relief are, upon the whole, less striking than those of

mountains or plateaus. Rivers cut channels into their surfaces, and valleys of mild relief are gradually developed.

280. The relief of plateaus.—The abrupt descent of plateaus toward adjoining areas gives such high velocity to the streams that gorges and canyons are often prominent features (Sec. 161). Waterfalls and rapids are also of frequent occurrence along the margins of steep descent. The variation in the hardness of the strata of which plateaus are composed is another cause of their erosion into features of striking irregularity. Prominent among the features resulting from irregular erosion are the table-shaped mounds with flat tops which are found on many arid plateaus. These formations have given rise to the name *table-land* as a synonym for plateau. In western Canada and in the western United States these table-lands are known as *mesas*. The flat top is composed of a horizontal stratum of great resistance, which remains after a great deal of the softer strata underlying and adjoining it has been removed by weathering and erosion. Gradually the margins of the projecting shelf break off from their own weight, and, finally, the whole top is destroyed. Other hard horizontal layers at lower levels may form a succession of tops, and thus mesas of different heights may exist upon the same table-land.

CHAPTER XXI

ISLANDS

Classification of Islands

281. General relationships.—In the chapter dealing with shore-lines, reference was frequently made to islands, because by virtue both of position and of mode of origin, many islands rank among the most important of shore features. There are many islands, however, which are far removed from coasts and which have not originated in the modification of shore-lines. Hence, when considered from the view-point of their relationships, islands are either *continental* or *oceanic*. Continental islands are parts of continental areas which have in some way been separated from the main masses, while oceanic islands are prominences rising from the beds of oceans and having no direct relationship to the great land areas of the world.

Continental Islands

282. The characteristics of continental islands.—Continental islands are either continuations of the ridges upon the great land areas and are composed of the same kinds of rock as these areas, or they are the accumulations of detritus eroded from the main land masses. They are usually separated from the latter by comparatively narrow and shallow bodies of water.

283. The origin of continental islands.—In many instances coastal lands of strong relief have sunk, until the less elevated portions are completely submerged and

the more elevated areas are left projecting above the sea.

Some of the world's largest islands have been separated from the continental masses in this way. Iceland and the British Isles, including the Orkney, Shetland, and Faroe Islands, represent the unsubmerged portions of a plateau that formerly extended from the north-western part of Europe to Greenland. Newfoundland became detached from the mainland of North America by the submergence of the area which is now the bed of the Gulf of St. Lawrence. The presence of coal formations in the strata under the Gulf proves that these strata were formerly above sea-level. On the western coast of Canada, Vancouver Island has been detached from the mainland by the sinking of the coastal region, and the consequent submergence of a mountain valley, which now forms the bed of the Strait of Georgia. Many

Courtesy of the Geological Survey, Canada
Fig. 151.—A fiord at Pt. Burwell, Labrador

of the small islands off the coasts of Norway and Scotland were likewise produced by the submergence of the connecting lands.

Islands are sometimes detached from the mainland

by erosion. Waves often so erode a coast as to isolate small masses of resistant rock (Fig. 116). Rivers sometimes cause the erosion of jointed rocks in such a way that irregular islands are formed (Fig. 65). The several groups of islands in the rapids above Niagara Falls are representatives of this type. Glacial erosion is also responsible for the isolation of coastal prominences, thus forming them into islands. Many of the islands on glaciated coasts, such as those of Norway, Labrador, and south-eastern Alaska, were formed by glaciers in their descent from the land to the sea (Fig. 151).

Islands formed from the sedimentary deposits of rivers have been described in the chapter on shore-lines (Sec. 212), and also in the chapter on rivers (Sec. 165). These include deltas, such as those at the mouths of the St. Clair, the Mississippi, and the Hwang Ho; off-shore bars, such as that inclosing Toronto Bay and those along parts of the Texas coast of the Gulf of Mexico; and alluvial islands that lie within the channels of rivers. Examples of the latter are found in many Canadian streams. They are due to the deposition of sediment at points where, for any reason, the speed of the current is checked, or to an obstruction that causes a division of the stream so that a part of the flood plain becomes inclosed between two channels.

Oceanic Islands

284. The origin of oceanic islands.—Among islands of the oceanic type are included those formed by the accumulation of material discharged during submarine volcanic eruptions, by which cones have been raised from the ocean bed above the surface of the sea (Fig. 152). These are frequently far out in the ocean and sometimes occur in groups or in chains. The Hawaiian Islands of

the Pacific and the Azores of the Atlantic originated in submarine volcanic action.

In some instances oceanic islands arose from the bed of the sea by the slow process of mountain building, and, in consequence of this, they occur in chains. The islands of Japan, the West Indies, and the New Zealand group were, for the most part, raised from the ocean bed by this process of crustal folding.

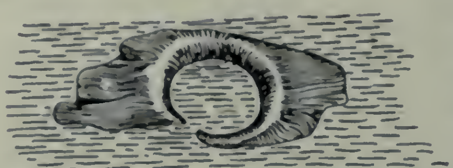


Fig. 152.—St. Paul's Rock, a volcanic cone in the Atlantic Ocean

By far the larger number of oceanic islands are composed of a stony framework, a considerable part of which is made up of limestone secreted by small animals called coral polyps. The shapes of the coral vary with the species of polyps that compose the colony. The branching varieties of coral play the most important part in the formation of reefs.

285. The conditions necessary for coral growth.—The distribution of coral islands over the ocean depends upon the suitability of the water for sustaining the life of the polyps. The following conditions are necessary for their existence: (1) The temperature of the water must never fall below 68°F. (2) The water must be shallow, because the polyps do not work at a depth greater than 120 feet. (3) The water must not be more or less salty than ordinary sea-water. Few coral formations are found in seas receiving large volumes of river water. (4) The water must be free from mud and river sediment. These conditions are found only between parallels 30° north and 30° south and on the eastern coasts of continents within these latitudes.

Hence the great coral formations of the world are on the east coasts of America, Asia, Africa, and Australia, toward which the trade-winds are continually moving the warm surface water of the ocean. The warm ocean currents occasionally extend the conditions suitable for coral growth beyond their usual latitudes, as in the case of the Bermudas.

286. Types of coral islands.—There are three distinct types of coral island formations: (1) the *fringing reef*, which lies close to a shore, being separated from it by a narrow, shallow lagoon; (2) the *barrier reef*, which runs parallel to the shore at a considerable distance from it. The inclosed water is frequently of sufficient depth and extent to permit of navigation by ocean-going vessels. The Great Barrier Reef extending along the eastern coast of Australia is 1,200 miles in length and is from twenty to one hundred and fifty miles from the shore. (3) The *atoll*, which is a circular reef inclosing a sheet of water (Fig. 153).

Courtesy of The Macmillan Co.
Fig. 153.—An atoll, Carolina Islands, Pacific Ocean

The reefs seldom rise more than twenty feet above the level of the sea, and in many cases parts of them are submerged. The hidden portions are serious menaces to navigation.

287. How a coral island is completed.—The coral polyp cannot build above the water, but branches of coral are broken off and thrown by the waves upon a slightly submerged reef. Sea-shells and sea-weeds are added to this, until the accumulated matter rises above the surface of the sea. Pieces of broken coral are ground into sand, which fills up the spaces between the branches of coral. Water containing lime solutions percolates through the mass and gradually cements it into solid limestone. Drifting pumice and sea-weed become stranded upon the beach, and these, mixed with coral sand, form the soil upon which seeds that are carried by winds and currents take root. Plant life invites bird and insect life, and an inhabited coral island, with its typical plants and animals, has been completed.

288. Darwin's theory of coral reefs. — Although the coral polyp can live and work only in shallow water, many barrier reefs and atolls arise from very deep seas. Several theories have been advanced to explain this anomaly, but no one theory has been found adequate to account for all the facts.

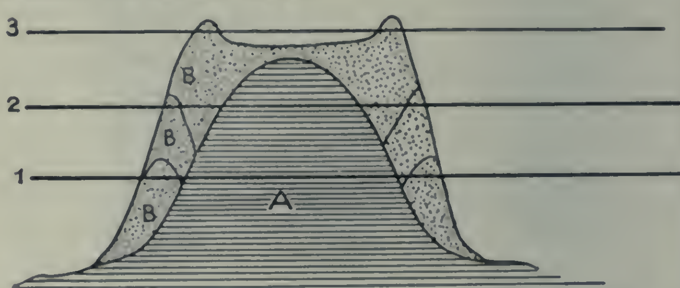


Fig. 154.—Illustrating Darwin's theory of deep-sea coral formation—*A*, original volcanic islands; *B*, *B*, *B*, coral formation. *1*, *2*, *3*, successivel evels of the sea at the fringing reef, barrier reef, and atoll stages, respectively

From investigations made during his voyage on H.M.S. *Beagle*, Darwin reached the conclusion that fringing

reefs, barrier reefs, and atolls are all of similar origin (Fig. 154). He concluded that all three are built around oceanic islands which have risen from deep sea-beds, usually by volcanic action. If the coral ring rose above the surface of the sea without subsidence taking place, a fringing reef was formed. If, after the fringing reef had reached the surface of the sea, subsidence occurred, the island and the base of the reef might be lowered as fast as the coral colony could build upward. In this way the fringing reef would be changed eventually into a barrier reef, and finally into an atoll.

Several observers have pointed out that atolls are found in areas that are rising as frequently as in those that are subsiding—a fact which exposes a weakness in Darwin's theory.

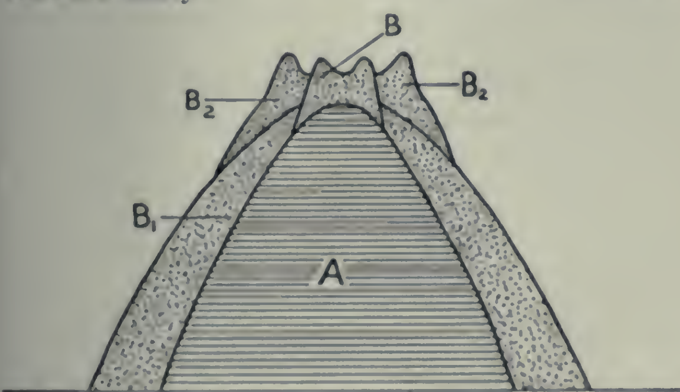


Fig. 155.—Illustrating Sir John Murray's theory of deep-sea coral formation—*A*, original volcanic cone; *B*, sea coral built above *A*; *B1*, coral debris from *B*, *B2*, coral built on a wide base and apparently rising from deep sea

289. Sir John Murray's theory of coral reefs.—Sir John Murray believed that every barrier reef and every atoll has its base upon a deep-sea plateau or upon the wave-denuded stump of a volcanic island (Fig. 155). The coral polyps build upon this base, and the great depth

of the barrier reef or of the atoll is accounted for by the fact that the coral branches which break off on the exterior of the reef slide down the steep sloping surface, and thus a wider foundation is gradually formed upon which the coral ring can be extended. Meanwhile the interior of the ring is disintegrating, because no new growth can take place in the inclosed water (Sec. 285), and the old coral is dissolved by chemicals contained in this water. Thus there is produced a narrow but ever expanding ring, which constitutes a barrier reef, if the island inclosed by it projects above the sea, or an atoll, if the island is wholly submerged.

Borings on one of the coral islands of the Ellice group in the South Pacific showed coral formations extending to a depth of at least 1,114 feet below the centre of the lagoon. This fact would appear to support the theory of Darwin, rather than that of Murray.

It is probable that both these theories, and even others, are required to account for all forms of coral islands.

CHAPTER XXII

THE SOLAR SYSTEM

Exercises Reviewing Previous Studies

(1) *Field observations of the sun.*—

Observe the time and the position of the rising and of the setting of the sun on or about Sept. 21st. Repeat these observations on the corresponding date of December, March, and June. Compare the duration of daylight on these days.

From an almanac obtain the exact time of sunrise and sunset on Sept. 1st, 10th, and 20th, and on June 1st, 10th, and 20th. Compare the duration of daylight on these days.

(2) *To find (a) an east-west line, (b) a north-south line, (c) the difference between solar noon and twelve o'clock noon by means of the sun.*—

(*a*) Select a smooth horizontal plot of ground. In the middle of this plot set a straight rod in a vertical position with the top of the rod four feet above the surface of the ground. With the rod as centre, describe on the ground a circle, radius three feet, or longer if necessary.

In the forenoon observe the point upon the circumference of the circle where the top of the shadow of the rod passes into the circle. Insert a short peg at this point.

Observe and mark the corresponding point when the top of the shadow crosses the circle in the afternoon.

Draw a straight line from one peg to the other. The line joining the two pegs is an east-west line.

(*b*) Carefully bisect the east-west line and draw a line from the point of bisection to the centre of the rod. The last line is a north-south line.

(*c*) Observe that the shadow of the rod grows shorter during the forenoon and longer during the afternoon.

At five-minute intervals between 11.30 a.m. and 12.30 p.m., mark the position of the tip of the shadow to determine when the shadow is shortest. Compare the position of this shadow with that of the north-south line.

The time of day when the shadow is shortest we shall call solar noon. Look at the clock and find whether solar noon occurs before or after twelve o'clock noon, or whether the two exactly coincide. Try this again in other months, especially in November and February if possible.

(*3*) *To find the angles of elevation of the sun, when on the meridian at your place of observation, on or about Sept. 21st, Dec. 21st, March 21st, and June 21st.*—

Use the rod as arranged for Exercise No. 2. Observe and mark by a peg the position of the tip of the shadow when it falls along the north and south line on Sept. 21st. Place a long ruler so that it rests with its lower end against the bottom of the peg and its upper portion upon the top of the rod. Measure the angle that the ruler makes with the surface of the ground. This is the angle of elevation of the sun at noon on Sept. 21st.

Make a drawing to scale, showing the rod, the ruler, and the angle.

Repeat the exercise upon each of the other dates given.

(*4*) *To study phenomena depending upon the spherical shape of the earth.*—

Observe and name the parts that can be seen in the case of several steamships that are at various distances from you.

Under what conditions can the smoke alone be seen?

(5) *Problems on time.*—

(1) It is 12 o'clock solar noon at Greenwich. Find the corresponding solar time at each of the following longitudes: 30°W., 30°E., 60°W., 75° 15′ E.

(2) It is 8 o'clock a.m., at a point in 45° west longitude. What time is it at Greenwich? What time is it at a place in 45° east longitude?

(3) It is 10 a.m. at Greenwich.

(*a*) What is the solar time at a point in 62° 40′ west?

(*b*) What is the solar time at a point in 50° 25′ east?

(4) (*a*) Find the difference in the solar times at two places *A* and *B*, *A* being in 79° 20′ west longitude, and *B* in 123° 10′ west longitude.

(*b*) What is the probable difference between the standard times of the places described in (*a*)?

(5) By means of an observation on the sun, a captain found that the solar time of the point at which his ship was located, is 2 hr. 16 min. slower than the solar time at Greenwich as obtained from the ship's chronometer. Find the longitude of the ship at the instant the observation was made.

Preliminary Experimental Work

(1) *To draw to scale an ellipse to represent the form of the orbit of the earth.*—(Scale 1 millimetre to 500,000 miles)

Loop a thread and tie the ends together so that the loop is 378 mm. long. Place two pins vertically in the drawing paper so that they are 6 mm. apart, and fix them firmly. Using a sharp-pointed pencil held inside the loop, draw an ellipse, as shown in Figure 156.

The points where the pins were inserted are called the *foci* of the ellipse. Mark the foci. Bisect the line between the foci. With this point as centre, and with

half the long diameter of the ellipse as radius, draw a circle. Compare the ellipse with the circle so described. Now draw a small circle, two mm. in diameter, around one of the foci to represent the sun.

Fig. 156.—Illustrating how to draw an ellipse to represent the orbit of the earth

Indicate the positions of the earth in aphelion, and in perihelion respectively. (Sec. 306).

Measure the distance between the centre of the circle representing the sun and each end of the long diameter. From these measurements calculate the distance from the centre of the earth (*a*) in aphelion, (*b*) in perihelion, to the centre of the sun.

(2) *To study the phases of the moon by observation.*—

Refer to the almanac and find the date of the next new moon. Look for the moon on that night and on several following nights. On which night do you first see the moon?

On several successive evenings measure the angle between the sun and the moon by sighting one leg of a compass on the setting sun and the other upon the moon.

How many degrees does the angle increase from one evening to the next? In what direction does the moon move around the earth?

Use the answers to the last questions in determining approximately how many days it takes the moon to move around the earth.

Make a drawing of the young moon, noting especially the directions in which the horns point.

Observe how many days are required for the moon to grow to a half disk.

In what part of the heavens is the full moon first seen?

Observe closely the times of rising for two consecutive nights, and find, as accurately as possible, the difference between these times.

Make a drawing of the waning moon, and compare the direction in which the horns of the waning moon point with that in which the horns of the growing moon point.

(3) *Observation exercise on shadows as a preparation for the study of eclipses.* —

(*a*) Place a lighted lamp (preferably having a frosted globe), or a ground-glass electric bulb on a table in a darkened room. (The parallel beam from a projection

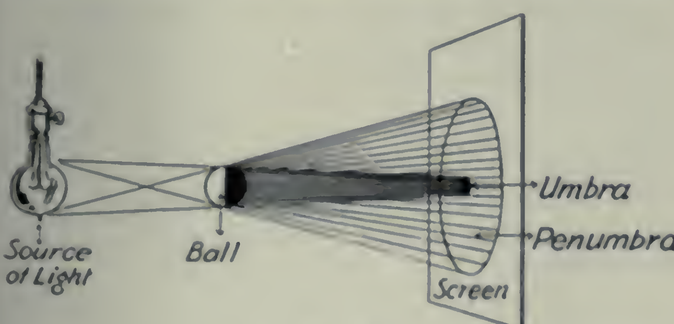


Fig. 157

lantern gives excellent results). Suspend a marble or a small ball at a distance of four feet from the light, and so arrange a white cardboard that the shadow of the ball may fall upon it (Fig. 157).

Move the cardboard back and forward until the shadow upon it is of uniform darkness.

Move the cardboard farther from the ball. Describe the changes that take place in the shadow, and distinguish the *umbra* and the *penumbra*.

Observe the umbra and the penumbra while the cardboard is being moved farther away, and also while it is being brought closer.

Make a small hole in the cardboard and place the eye behind this hole. Describe the effect of the ball upon the appearance of the source of light (*a*) when the umbra falls upon the hole in the cardboard; (*b*) when the penumbra falls upon the hole in the cardboard.

(*b*) Repeat the experiment, using the school globe instead of the white screen. Rotate the globe.

The Members of the Solar System

289. What is the solar system?—The science of astronomy has shown that our earth is a member of a group of bodies revolving about the sun. This group, which has the sun as a central controlling member, is called the solar system, (Latin–*sol*, the sun). In the solar system are included the *sun*, eight *planets*, the *moons* or *satellites* of these planets, a number of *comets*, and innumerable smaller bodies called *asteroids*, *meteors*. and *meteorites*.

The Sun

290. The heat of the sun.—To describe the sun as an enormous ball of fire having a diameter of 865,500 miles conveys very little conception either of its magnitude or of its intense heat. When we consider that the diameter of the sun is nearly four times as great as the distance from the earth to the moon, and that more than

a million earths could be placed within the space occupied by the sun, we begin to realize faintly how huge the sun really is. The dazzling brightness of the surface of the sun is due to the intense heat of luminous gases. The white heat of a blast furnace will melt nearly all metals and rocks, but so intense is the heat of the sun that any material placed at its surface would be not only melted by it, but would also be converted into vapour. Imagine a layer of ice nearly half a mile thick covering the whole surface of the sun; the heat of the sun would melt it in one hour. The sun sends out sufficient energy to supply each of two thousand million earths like our own with the same amount of heat as is received by the earth.

This enormous mass of highly heated vapour, with its possibilities of expansion, but yet having a tendency to contract under the action of a gravitation almost thirty times as great as that of the earth, is the theatre of tremendous explosions and convulsions. Frequently the evidences of these explosions are visible from the earth as *sun spots* and *solar prominences*, which alter the usual appearance of the sun.

291. The surface of the sun.—The dazzling surface which we see, and which radiates the sun's light, is called the *photosphere* (light sphere). To the naked eye it appears of uniform brightness, but when it is viewed through a telescope, it is seen to have a mottled appearance. The brighter parts of the mottled surface are intensely luminous and are sometimes spoken of as "rice-grains." Overlying the photosphere, but visible to the naked eye only during solar eclipses, is a layer of reddish colour which is called the *chromosphere* (colour sphere). Stretching outward from the chromosphere is an envelope called the *corona*. This appears as a halo of pale white light which extends into space for distances

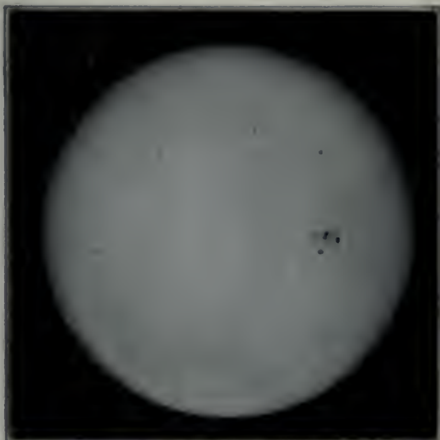
varying from 1,000,000 to 3,000,000 miles. The corona is so faint that it is invisible when the earth's atmosphere is illuminated, but it becomes visible during a total eclipse of the sun (Fig. 158). During an eclipse of the sun solar prominences, usually composed of luminous

Courtesy of C. A. Chant
Fig. 158.—Total eclipse of the sun, showing corona

gases of a red colour, are seen streaming outward from the chromosphere to distances ranging up to 500,000 miles.

292. Spots on the sun.—Sun spots are seen as dark blotches upon the surface of the sun (Fig. 159). The smallest appear like mere specks, but in reality each is at least several thousand square miles in area. Some of the largest spots are of very great size. One was observed in February, 1892, of such magnitude that it would require thirty-five times the earth's surface to cover it. The surface of the sun is seldom entirely free from spots, but their number varies between a maximum and a minimum in fairly regular cycles that have an average length of approximately eleven years. Of the many theories of the origin of sun spots, the one most generally accepted is that they are due to

enormous volumes of gases rising through the photosphere. The expansion of the rising gases causes them to become cooler and less bright.



Courtesy of Yerkes Observatory
Fig. 159.—Surface of the sun, showing sun spots

The Planets

293. Comparative description of the planets.—The eight planets named in the order of their proximity to the sun are *Mercury*, *Venus*, *Earth*, *Mars*, *Jupiter*, *Saturn*, *Uranus*, and *Neptune*. They are dark bodies, which, however, shine with the reflected light of the sun, and so, viewed from the earth, look much like stars. Mercury, Venus, and Mars are solid spheres, but the low densities of Jupiter, Saturn, Uranus, and Neptune give ground for belief that these are largely gaseous. Mercury, the smallest planet, has a diameter only three-sevenths as great as that of the earth; while Jupiter, the largest of the family, has a diameter eleven times as great as that of our planet (Fig. 160). The climates

of the planets present some interesting differences. Owing to its nearness to the sun Mercury receives nearly seven times as intense heat and light as is received by the earth, while Neptune is so far distant from the sun that the amount of radiant energy reaching it is very slight indeed. Mars shows distinct evidence, by the variations in its white polar caps, which

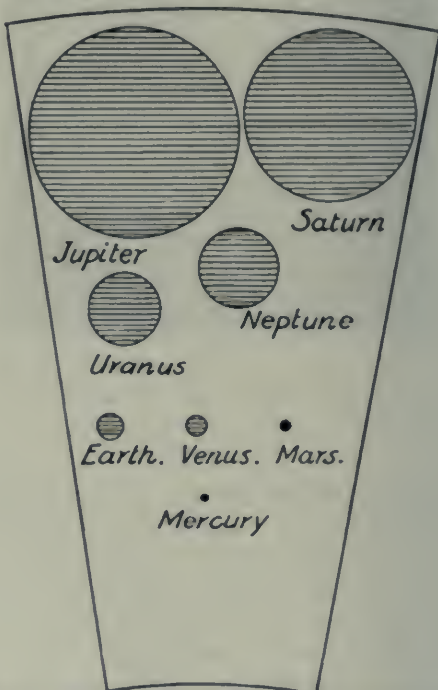


Fig. 160.—Diagram representing the relative sizes of the sun and the planets. The planets are shown within a figure that represents 1-48th of the sun's disk

apparently consist of ice and snow, of having seasonal variations somewhat resembling those of the earth. Some astronomers believe that Venus, too, has a succession of seasons.

294. Satellites of the planets.—With the exception of Mercury and Venus, each planet has one or more moons, or satellites, which revolve around it and supply it with reflected light. Jupiter, the largest of the planets, has nine satellites. The attendants of Saturn are the most numerous, comprising ten moons and a host of smaller bodies that are crowded together in a series of concentric rings which encircle the planet (Fig. 161).

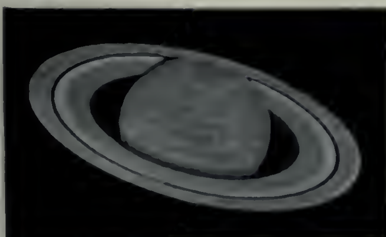


Fig. 161.—Saturn with rings

295. The planets as they appear in the heavens.—As viewed from the earth, the planets appear very much like stars. They may be distinguished from stars by the fact that, with the exception of Mercury, they do not twinkle, except when they are near the horizon. When seen through a telescope they are round bodies of distinct size, while stars always appear as points of light. Further, if we observe the planets for several successive nights, we find that they have changed their position in relation to the stars, while the stars apparently retain the same relative positions to one another. In fact, to this characteristic the planets owe their name, which comes from a Greek word meaning a wanderer.

Mercury and Venus are our chief morning and evening stars, because they are seen most clearly either in the eastern sky before sunrise or in the western sky after sunset. Mercury is of a pale ashy colour, and is so small

and so close to the sun that it is seldom seen. Venus, however, is, next to the sun and moon, the brightest of all the heavenly bodies.

Because it presents many phenomena similar to those of our earth, Mars is of particular interest to us. Through the telescope white areas are observed at its poles. Since these increase and diminish with the seasons, they are thought to be accumulations of ice and snow similar to those on the earth. A number of long straight

Courtesy of C A Chant

Fig. 162.—Snow caps and "canals" on the surface of Mars

streaks have been observed upon the surface of Mars (Fig. 162). These are more pronounced at certain times than at others. Some astronomers have interpreted them as natural water channels, which are better seen as vegetation grows along them. Others have claimed that they are canals constructed by intelligent beings for purposes of irrigation. Observations of this planet, however, lead to the conclusion that its atmospheric conditions are so unlike those of the earth that, if Mars

has any inhabitants, they must be very different from those of our planet.

Jupiter is one of the most brilliant of the heavenly bodies. Its brightness is due to its size and to the high reflecting power of its surface.

The Earth

296. The Earth a sphere.—We can all, no doubt, recall the shock to our confidence in our senses when first we were told that the earth was not a flat object, but was a great sphere whirling rapidly through space. So stubbornly did the ancients oppose these views, that Thales and Pythagoras, who taught these theories six centuries before the Christian Era, were compelled to desist from teaching them. Thoughtful travellers of those early days were perplexed in their efforts to explain "the bended sea," and were also unable to account for the fact that the northern stars appeared closer to the horizon as a traveller journeyed south, although the same stars rose higher above the horizon if the traveller's course was northward. The conviction grew slowly through the centuries that these phenomena were inconsistent with the theory of a flat earth, and in the days of Christopher Columbus the theory of the spherical form of the earth was accepted by many.

297. Proofs of the spherical shape of the earth.—The proofs of the spherical shape of the earth have become commonplace. Who, when watching a steamer disappear on the horizon, fails to associate the order of disappearance—first the hull, then the funnels, and last of all, the smoke, with the curvature of the earth's surface? The fact that this is the order of disappearance wherever observed and in whatever direction the ship is sailing, proves that the surface of the earth curves

in all directions. The circumnavigation of the earth along a course, which though not in a straight line, can nevertheless be shown to be equivalent to a continuous east and west course, has frequently been accomplished. The following are also familiar proofs:

(1) The fact that there is an increase in the distance to the circular horizon as the elevation of the observer becomes greater.

(2) The fact that the earth's shadow as cast upon the moon during an eclipse is such as only a sphere could cast.

298. The earth an oblate spheroid.—In 1672, Richer, a French astronomer, had occasion to move his pendulum clock, that kept accurate time, from Paris to Cayenne in French Guiana. He was surprised to find that the clock now lost time. An investigation led to the conclusion that, since the pendulum swung more slowly at Cayenne than at Paris, the attraction of gravity upon it must be less. This could be accounted for by assuming that the radius of the earth near the equator is longer than the radius through Paris. Repeated tests with pendulums, and also measurement upon the earth's surface at different places, confirmed the conclusion that the longest radii of the earth are those near the equator, and that the shortest are those passing through the poles. We know, therefore, that the earth is an *oblate spheroid*, bulging at the equator and flattened at the poles, the polar diameter being about $\frac{299}{300}$ of the length of the equatorial diameter.

299. The size of the earth. — Eratosthenes, a noted Greek astronomer, about 240 B.C. determined the circumference of the earth, basing his calculations upon observations of the shadows cast by the sun at Alexandria and at Syene (Assuan). He found the circumference of the earth to be approximately 25,000 miles, giving a diameter of about 8,000 miles.

Accurate computation gives 7,926.57 miles as the equatorial diameter, and 7,899.98 miles as the polar diameter.

The Rotation of the Earth

300. Description of the rotation of the earth.—Just as a top whirls around with the peg thrust through its centre serving as an axis, so the earth rotates upon its axis. In the case of the earth the axis is not a real peg but an imaginary one. The ends of this axis are called the north and south poles. The time taken for one complete rotation is called a day. Any point on the earth's equator travels about 25,000 miles in that time, that is, at a speed of more than 1,000 miles per hour. But notwithstanding this great speed, the movement is so steady and free from jarring effects that we fail to perceive it. The unvarying character of the movement is due to the fact that land, and air, and water, all form part of the rotating mass and all rotate with the same velocity, with certain exceptions, as for instance, the movements of the water of the ocean in currents (Sec. 84), and the movements of the air in certain kinds of winds (Sec. 45).

301. Proofs of the earth's rotation.—A direct proof of the earth's rotation is furnished by the following experiment: A ball is dropped from a high tower and is observed to strike the ground to the east of a point vertically below that from which it falls. Ordinary observation teaches us that, if a body is moving in any direction at a certain rate, it tends to continue this movement, unless some force acts upon it tending to alter its speed or to change its direction. The fact that the ball alights east of a point which is vertically below that from which it is released indicates that the earth is

not at rest, for, if it were, the ball would fall vertically. It also indicates that the ball, at the instant it begins to fall, has a more rapid easterly movement than that of the point vertically below it. This shows that the earth rotates toward the east, for such a rotary motion would give to the ball, because it is farther from the axis of rotation, a more rapid easterly motion than the point on the ground has. This experiment has been tried many times by various investigators, and the deviation of the ball toward the east is appreciable, though very slight (Fig. 163).

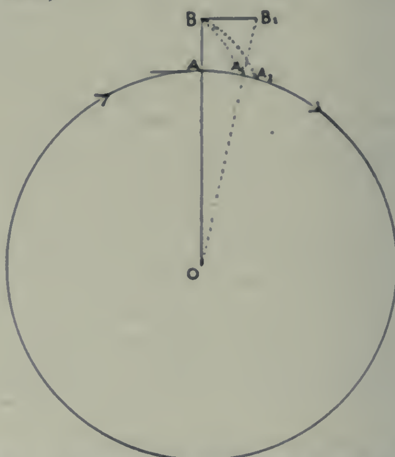


Fig. 163.— The top *B* of a tower *AB* is farther from the centre of the earth than the bottom *A*, and, consequently, travels eastward, on account of the earth's rotation, faster than *A*. During the time the body is falling to the earth it moves eastward to *A2*, while the foot of the tower moves to *A1*. Thus it reaches the earth some distance east of the foot of the tower

In addition to the above proof, we have the facts of the directions of the trade-winds (Sec. 46) and cyclonic whirls (Sec. 54), for which no satisfactory explanation has been given except that based upon the rotation of the earth from west to east.

Though the theory of a stationary sun and moving planets is many centuries old, dating from the teachings of Pythagoras, it may be said to have been established in comparatively modern times by a Polish astronomer, Copernicus (1470-1543). Even during the age of Copernicus the intellectual leaders were so conservative that, for more than one hundred years, these ideas were not accepted, and the conclusions of Galileo, whose invention of the modern telescope made it possible to observe the rotation of the other planets, were likewise rejected by many.

Twilight

302. The succession of day and night.—As you have already learned in your earlier studies in geography, the rotation of the earth upon its axis once in approximately every twenty-four hours, by bringing successive points of the earth's surface within the reach of sunlight, is the cause of the succession of day and night. In physical science we learn that a beam of sunlight is composed of rays that are transmitted in parallel straight lines. Hence, one half of the earth's surface will be in the sunlight at any instant of time. Day and night, however, are not sharply separated by the rising and the setting of the sun. On the contrary, night gradually changes into day and day into night through intervening stages of twilight. The circle separating the illuminated areas of the earth's surface from the area that is, in darkness, is called the *twilight circle.*

303. Cause of twilight.—If a large sheet of ground glass or white blotting-paper is held so that the rays of the sun coming in through the window strike it, the light is reflected and scattered by the glass and is found to illuminate adjacent surfaces, but less brightly than direct sunlight. The particles of the atmosphere, par-

ticularly dust and water vapour, act very much like the rough surface of the sheet of glass. These scatter and reflect the sunlight that passes into the atmosphere when the sun is invisible below the horizon. The amount of scattering varies with the distance of the sun below the horizon. The effect ceases to be noticeable when this distance is about 18°.

304. Variation in the length of twilight.—Since the sun drops nearly vertically below the horizon within the tropics, the duration of twilight can be estimated as the time required for the sun to pass through 18°, that is, $\frac{18}{15}$ of 1 hr.=1 hr. 12 min. In northern and southern latitudes, owing to the inclined path of the rising and setting sun (Fig. 11), the duration of twilight is greater, reaching a maximum at the poles, where the sun, after disappearing below the horizon, remains for many weeks at a distance of less than 18° below it. During the summer the sun, in our latitude, takes a longer time to drop 18° below the horizon than during the winter. Therefore, our twilight is of longer duration in summer than in winter.

The Revolution of the Earth

305. The time occupied by a revolution.—We now turn to a consideration of the second of the earth's movements, namely its revolution around the sun. By this movement the earth travels around the sun once every year, or to express the measurement of the time more definitely, the interval between the sun's apparent crossing of the equator in the spring, and its crossing in the succeeding spring, is a *tropical year*. The average length of a tropical year is 365 days, 5 hrs., 48 min., 45.51 sec. In our calendar the ordinary year is 365 days in length. The addition of one day to the month

of February of every fourth year (leap year) more than compensates for the difference of 5 hrs. 48 min. 45.51 sec., and the discrepancy is made up by making the year of each century whose number is not exactly divisible by four hundred, a year of 365 days. For instance, the year 1600 was a leap year, but the year 1900 was not.

306. The orbit of the earth.—The path in which the earth travels in its journey around the sun is called the earth's orbit. This path is an ellipse, and the plane in which it lies is called the *plane of the earth's orbit.* The earth's axis is not perpendicular to the plane of the orbit, but forms an angle of approximately 23½° with the perpendicular. When the earth is at that point of the orbit which is farthest from the sun, it is said to be in *aphelion* (Greek–*apo*, from; *helios*, sun),

Fig. 164.—Surface of the moon

and when it is in that part of its orbit which is nearest to the sun, it is said to be in *perihelion* (Greek–*peri*, around; *helios*, sun). The earth is in aphelion about

July 1st, and it is then approximately 94,500,000 miles away from the sun, and it is in perihelion about January 1st, at which time it is about 91,500,000 miles distant from the sun.

The Moon

307. The source of the moon's light.—The moon, like the earth, is a non-luminous sphere, but it appears bright because it reflects the light of the sun in the same way that a speck of dust appears bright and luminous when it reflects to our eye the light of the sunbeam in which it is floating (Fig. 164).

308. The size of the moon and its relation to the earth.—The moon is one of the smaller of the heavenly bodies, having a diameter of 2,163 miles—somewhat

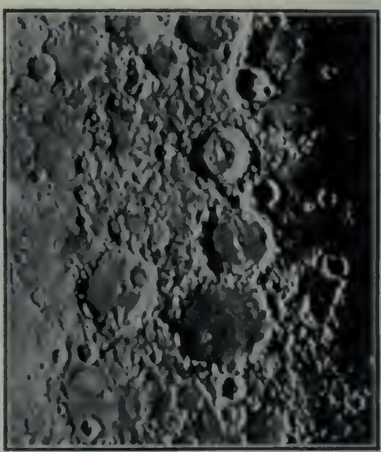


Fig. 165.—Volcanic craters on the surface of the moon

greater than one-quarter of that of the earth—and a volume about one-fiftieth of that of our planet. It is conspicuous in the heavens chiefly because of its nearness to us. It travels around the earth in an elliptical orbit, the

longest radius of which measures about 240,000 miles. The moon moves about the earth in the same direction as that in which the earth rotates. When the moon is at that point in its orbit which is closest to the earth, it is said to be in *perigee* (Greek – *peri*, around; *ge*, earth), and when it is at that point in its orbit which is farthest from the earth, it is said to be in *apogee* (Greek – *apo*, from).

309. Physical phenomena of the moon's surface.—Astronomical science reveals many interesting facts about the moon. It shows that the moon's surface is solid. The face of the "Man in the Moon" is due to the reflection from sunlit mountains interspersed with shaded valleys. Many of the mountains resemble extinct volcanoes with wide, gaping craters, surrounded by deep cup-shaped rims (Fig. 165). No atmosphere, cloud, or moisture bathes the barren surface of the moon, and as there is only one lunar rotation during each revolution round the earth, the average length of a night on the moon is equal to about fifteen of our days of twenty-four hours. Since there is no atmosphere to cause twilight, to prevent the radiation of heat from the moon's surface, or to transmit sound, the long nights would, to human senses, be intensely dark and cold and mysteriously silent.

310. The phases of the moon.—The succession of apparent forms through which the moon passes during a lunar month is known as "the phases of the moon." These changes are due to the revolution of the moon around the earth, and the consequent variation in the position of the moon in relation to the earth and the sun. These facts may be explained by means of Figure 166, in which *S* represents the sun, *E* the earth, and 1, 2, 3 . . . 8, the moon in eight successive positions in its orbit.

In each position one-half of the moon is lighted up by the sun. In position No. 1, the illuminated half of the moon's surface is turned away from the earth, and the moon is invisible. At this time the moon is said to be

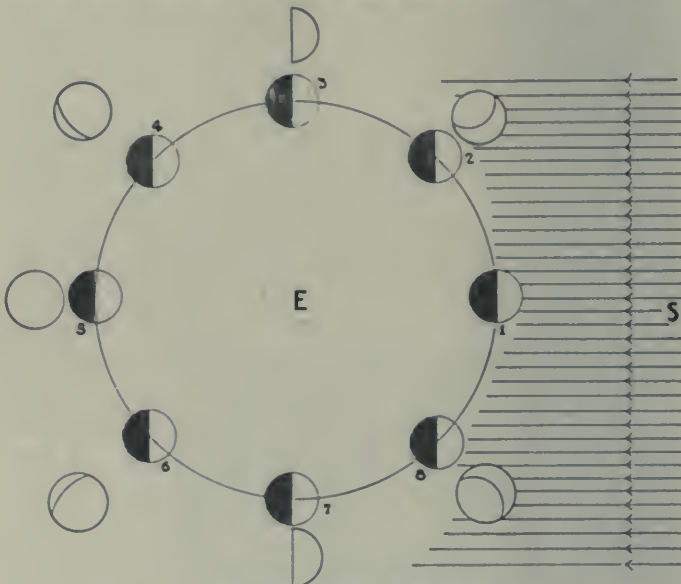


Fig. 166.—Phases of the moon

new. On succeeding evenings the moon appears as a narrow crescent. This is the *young moon*, although commonly called the new moon. Its shape is due to reflection from a part of the margin of the spherical surface of the moon. In position No. 2, a part of the illuminated surface is visible from *E*, and the moon is described as a *growing moon*. As the moon is now moving farther from its position in line between the earth and the sun, it is seen higher in the heavens upon each successive evening until it reaches position No. 3. This represents the moon at its first quarter, when it is

seen as a *half moon.* The moon continues to grow until it reaches the second quarter, when it is a *full moon*, as shown in No. 5. The whole of the illuminated half is now turned directly toward the earth. In No. 6, the moon is shown as *waning*, also in No. 7, in which the third quarter of the moon is shown, and in No. 8, the *old moon* is represented, in which only an illuminated crescent is seen from the earth.

ECLIPSES

311. The cause of solar eclipses.—When an opaque ball is placed between a large luminous body and a screen, the shadow cast upon the screen has a dark central portion called the *umbra*, and a marginal portion which is less dark and is known as the *penumbra.* Since the umbra is a section of a cone of shadow that has its base at the ball, it may be made to disappear from the screen by moving the latter a sufficient distance from the ball.

When the moon, in its revolution around the earth, passes between the sun and the earth, so that the sun, the moon, and the earth are in a straight line, a shadow

Fig. 167.—Total eclipse of the sun—Moon in perigee
Total eclipse from *A* to *B*. *P*, path of total eclipse. *R R*, rays of the sun falling between *A C*, and *B D* and preventing total eclipse outside of *A B*

is produced similar to that described in the last paragraph. When viewed from the part of the earth upon which this shadow falls, the sun is partly or wholly obscured. We call this a *solar eclipse*, that is, an eclipse

of the sun. Solar eclipses can occur only at the time of the new moon.

312. Solar eclipses are of three kinds.—Solar eclipses may be *total*, *annular*, or *partial*. The first occurs when the moon is in or near perigee. A total eclipse is then seen from the portion of the earth's surface upon which the umbra falls (Fig. 167). During a total eclipse the

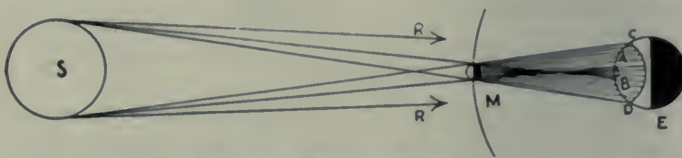


Fig. 168.—Eclipse of the sun
Between *A* and *B* the moon will appear as a dark disk with a ring, or annulus, of the sun surrounding it, as shown in Figure 169. Between *A* and *C* and also between *B* and *D* the eclipse will be partial, as in Figure 170.

stars become visible, and the solar prominences may be seen surrounding the sun.

Annular eclipses occur when the moon is in or near apogee. Owing to its distance from the earth when in this position, the moon appears smaller than the sun and does not completely cover the surface of the latter

Fig. 169

Fig. 170

(Fig. 168). Hence, the observer sees a ring of light surrounding the dark area that obscures the centre of the sun (Fig. 169).

Partial eclipses occur when the moon passes over an edge of the sun's disk, so that only a portion of the face of the sun is obscured (Fig. 170).

313. The cause of eclipses of the moon.—Lunar eclipses are caused by the moon passing through the shadow of the earth. This shadow stretches out along the plane of the earth's orbit, and if the moon is at or near this plane at the time of full moon, it will pass through this shadow.

314. Two kinds of lunar eclipses.—Lunar eclipses may be either *total* or *partial.* The eclipse of the moon is total if the whole surface of the moon passes within

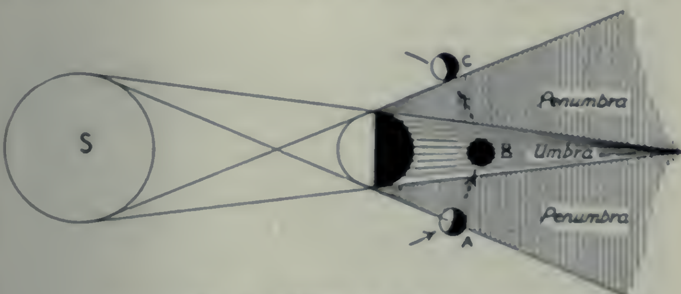


Fig. 171.—Eclipse of the moon
A—Eastern portion of the moon entering penumbra
B—Total eclipse
C—Western portion of the moon passing out of penumbra

the umbra so that it receives no direct rays from the sun (Fig. 171). During a total eclipse the moon is of a dull copper colour. If the moon passes partly within and partly without the umbra, the part within the umbra receives no light from the sun, while the remaining portion receives light from part of the sun's surface. In this case the eclipse is said to be *partial.* If the moon passes entirely within the penumbra, there is no true eclipse, but only a diminution of brightness.

If the orbit of the moon were in the same plane as

that of the earth, there would be an eclipse of the sun at every new moon and an eclipse of the moon at every full moon. The orbit of the moon is, however, inclined at an angle of about 5° to the plane of the earth's orbit, and this reduces the number of eclipses to a possible maximum of seven a year, for an eclipse is possible only when the moon is at or near a point of intersection of the planes of the two orbits at the time of a new or a full moon.

Comets

315. The movements of comets. — Occasionally, strange bodies of irregular form make their appearance in

Courtesy of the Yerkes Observatory
Fig. 172.—Halley's Comet

the sky, and, after moving across it, either disappear entirely, or are not seen again for many years. These bodies are called comets, and their great size, erratic

movements, and weird brightness have always appealed to the superstitious elements in man. In reality, the comets appear to be quite harmless, and, even though their tails occasionally brush against a planet, they cause no alteration or displacement of the latter.

316. The structure of comets.—Comets which are visible to the naked eye are usually composed of a star-like part called the *head*, containing a small bright centre called the *nucleus*, and a faintly luminous, hazy part called the *tail*. Comets which can be seen only through a telescope are frequently in the form of an irregular, nebular mass, in which neither head nor tail can be distinguished until the comet approaches the sun. When the comet is close to the sun, its tail becomes much larger and always streams out in a direction away from the sun.

317. The volume and mass of comets.—The heads of comets vary in diameter from 10,000 to 500,000 miles, and a few even larger have been observed. A comet that appeared in 1811 had a head 1,250,000 miles in diameter. The tails of comets sometimes reach enormous lengths, occasionally even 100,000,000 miles—a distance greater than that from the earth to the sun. Even though a comet may have an enormous volume, the quantity of matter which it contains is comparatively small. It has been estimated that the mass of one of the largest is not more than one-millionth of that of the earth. The smallness of the mass of comets is shown by the fact that they exert very little influence upon the other heavenly bodies. In 1886 a comet swept across the satellite system of Jupiter without influencing the movements of the members to any measurable extent.

Meteors

318. What meteors are.—Upon almost any clear starlight night, bodies resembling stars can be seen shooting across the sky at irregular intervals. These so-called shooting stars are *meteors*. A meteor is a mass of matter which, as it passes through space, comes near to the earth at a speed ranging from ten to forty miles per second. Upon entering the atmosphere of the earth it is rendered luminous by the burning of its surface layer, which is intensely heated by friction between its surface and the air. The products of the combustion slowly fall to the earth if they are solid, or mingle with the atmosphere if they are gaseous. There is good ground for believing that meteors are disrupted comets.

319. Number of meteors.—It is often possible to count from ten to fifteen meteors within an hour, and since an observer can watch only a small fraction of the area of the sky, it is evident that the total number of meteors of visible size that enter the atmosphere is very great. The number per day has been placed as high as twenty millions. Occasionally there are showers of meteors, and they appear in the sky, not singly, but in swarms. A conspicuous shower of meteors is seen during the second week of August every year. At this time the earth is at that point in its orbit which intersects the orbit of a cluster of meteors known as the *Perseids*. They are given this name because they seem to radiate from the constellation Perseus. A similar shower of meteors known as the *Leonids* occurs about the middle of November.

320. Meteorites.—Sometimes bodies ranging in weight from a few grains up to many pounds, dash through the earth's atmosphere with a loud roar, which frequently ends in an explosive report as the mass falls to the earth. These bodies are *meteorites* (Fig. 173). The

striking appearance of meteorites, due to their surface being raised to white heat by friction with the atmosphere, has led to their being popularly called *fire-balls*. The meteorites which are found are usually of a stony nature,

Courtesy of the Geological Survey, Canada

Fig. 173.—Meteorite found in Annaheim, Sask., 1916

but some are composed almost wholly of iron and nickel. Meteorites are usually believed to be meteors that are so large that they reach the earth before they are completely vaporized and pulverized.

Early in the evening of August 13th, 1904, two meteorites fell in the neighbourhood of the village of Shelburne, Grey County, Ontario (Fig. 174). The brilliant flash was seen more than 60 miles, and the accompanying sound was heard over 35 miles away. Two stones were found, one weighing $27\frac{3}{4}$ pounds, the other $12\frac{1}{2}$ pounds. The distance between the points of fall was about three-

quarters of a mile. The two stones fitted together as shown in Figure 174.

The Nebular Hypothesis

321. Introduction.—The human mind has grasped the plan of the universe sufficiently to recognize that there is a principle of unity underlying it all. For instance,

Fig. 174.—Shelburne meteorite

several facts indicate a common origin for the members of the solar system. The presence of the same component elements in the sun and the earth, and, presumably, in the other members of the system, the fact that the sun and all the planets and their satellites (with a few exceptions which can be explained) rotate and also revolve in the same direction, and the additional fact that the orbits of the planets are all practically in the same plane, are strong indications that the members of the system are derived from a common source. In the effort to account for this common origin several

theories have been presented. Of these, the one that has been most generally accepted until recently was first proposed in 1775 by the German philosopher, Kant, and again, with amplifications, in 1796 by the French astronomer, Laplace, and is known as the *nebular hypothesis*.

322. Outline of the nebular hypothesis. — The nebular hypothesis assumes that long ages ago all the matter that now composes the solar system was in the form of a rotating mass of very hot, thin vapour, extending beyond the bounds of the solar system as it now is. The denser portions of this vaporous mass attracted those of lesser density, and they were all drawn together until a common centre of gravity was developed. Along with a diminution in volume in response to gravitation, came an increase in the speed of rotation. The velocity of rotation of the equatorial zone finally became so great that it created such a strong centrifugal force at this region that the mass flattened at the poles and bulged out at the equator until it assumed the form of a disk. In later ages the gradual shrinking of the mass, resulting partly from the escape of heat, gave rise to a still greater speed of rotation, until at last the centrifugal force so far exceeded the attraction of gravity toward the centre of the mass that a succession of concentric rings broke away from the outer margin, leaving the inner portion of the mass free to shrink toward the centre. From this central portion the sun originated. Each of the rings so thrown off cooled and contracted, and its substance gathered into a planet. This accounts for the different distances of the planets from the sun. Cooling and shrinking caused an increase in the rate of rotation of each planet, and the centrifugal force produced a bulging of its equatorial zone, so that some of the planets cast off rings which became satellites.

The nebular hypothesis explains many facts connected with the solar system, such as the similarity of composition of the members and the rotation of the planets in the same direction: and it also accounts for the heated interior of the earth, and likewise for its spherical form. On the other hand, the hypothesis is discredited by certain geographical facts. For instance, if the earth had its origin in a highly heated mass, as this hypothesis assumes, its atmosphere and hydrosphere must have always been upon its outer surface, since these would be the last to condense. But, to account for the shrinking necessary to permit of mountain building,

Courtesy of Yerkes Observatory
Fig. 175.—Spiral nebula

it would appear necessary for the earth to begin as a solid with a large portion of the volatile atmosphere and hydrosphere contained within it. The expulsion of these by heat would afford sufficient cause for shrinkage.

The Planetesimal Hypothesis

323. Outline.—A more recent theory, known as the *planetesimal hypothesis*, assumes that the original constituents of the earth and the other planets were small cold bodies to which the name *planetesimals* (little planets) has been given. These moved in orbits about a large nucleus which formed a common centre, and the whole constituted a great spiral nebula similar to the spiral nebulae that still exist in the heavens (Fig. 175). The sun developed from the central nucleus. The planetesimals gradually gathered around a number of knots, or centres, and each aggregation finally formed a planet with one or more satellites. The gathering of the scattered planetesimals into knots is explained as being due chiefly to the coming together of these bodies as they met at the crossings of their slightly different orbits. Gravitation acted only as a secondary force to attract and to bind the bodies together.

According to this theory, the heat of the earth's interior is largely due to compression as the masses were drawn toward the centre. As a direct result of the compression and the heat, the more volatile components have been gradually forced from the interior of the earth and now constitute the atmosphere and hydrosphere. This, it is claimed, explains the enormous quantities of steam emitted by volcanoes, and also accounts for a large part of the shrinkage requisite for mountain folding.

324. Conclusion.—Though the above theories and all others that have been proposed are inadequate for explaining all they are intended to explain, they are, nevertheless, valuable expressions of the efforts of man to solve the problem of the principle of unity in the universe.

CHAPTER XXIII

THE OTHER HEAVENLY BODIES

Preliminary Experimental Work

(*1*) Using Figure 177 or Figure 178, look at the sky on the date and at the hour indicated on the map and locate the Great Dipper and the Pole Star. Observe the Dipper for several evenings and at different hours of the evening. Does it change in position? Repeat the observation a month later.

(*2*) *To find the approximate latitude of your home by means of the Pole Star.*—

Take a wooden strip *A*, about 18 inches long and $1\frac{1}{2}$ inches wide, with straight edges, and by means of a screw fasten it near the top of a post about 6 feet long, pointed at the other end so that it can be stuck in the ground. Next, carefully graduate 90 degrees of a circular arc on a white card (see *C* in the figure). The radius of the arc should be about 6 inches. Tack the card on the strip *A*, being careful to have the diameter

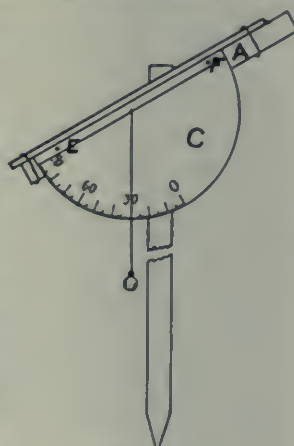


Fig. 175

EF parallel to the upper edge of the strip. Drive a pin at the centre of the circle, and from it hang a small

weight by means of a black thread. Fix a small tube (a pea-shooter) on the top of the piece *A* by string or rubber bands (Fig. 175).

If now the piece *A* is level, the thread will hang at 0° on the arc, and if it is tilted, the angle turned through will be read directly on the graduated arc.

To use the instrument, stick the upright firmly in the ground and turn it about until the tube faces the Pole Star. Then look through the tube and patiently work with it until you see the Pole Star through it. Try to adjust it so that the Pole Star is at the centre of the open end. To do this you may have to illuminate the end slightly with a flashlight. Now take the reading on the arc. Then push the piece *A* out of adjustment and try another reading. Do this (say) five times, and take the average of the values obtained. This will be the elevation of the Pole Star.

To a traveller who is at the equator, the Pole Star is seen on the northern horizon. As he journeys northward, the Pole Star rises one degree above the horizon for each degree of north latitude. Hence, the latitude of any place may be found approximately by measuring the elevation of the Pole Star.

(4) *To show the movement of the stars in the sky.*—

Focus your camera for infinity, support it firmly, and point it toward the Pole Star, being careful to keep it away from any strong neighbouring electric lights toward the north. Make an exposure of several hours' duration.

On another evening repeat the experiment, pointing the camera at an angle of 45° upward from the southern horizon. An exposure of fifteen minutes will be sufficient for this experiment.

THE STARS

325. Introduction. — The light which we receive from the planets and their satellites is only reflected sunlight, but far beyond our system are hosts of bright bodies shining by their own light. These are the *fixed stars*. They are suns, and the spectroscope tells us that they are composed largely of the same substances as our sun, though they differ somewhat in their physical conditions. They are at different stages in the process of their development. Some of them are hotter and more gaseous than our sun, while others are cooler and hardly shine at all. The former are pearly white, the latter dull red.

These stars are said to be *fixed*, because to ordinary observation they have always the same relative positions; but the measurements of modern astronomy are so refined that we have been able to prove that most of them are in motion. But the change of position is so small that, if the ancient Chaldaean astronomers (2000 B.C.) could again view the sky, they would hardly be able to detect any change in the relative positions of the stars.

326. The number of stars.— The number of stars which can be seen with the naked eye is only about 5000, and fewer than half of these can be seen at any one time. But an ordinary opera-glass brings out at least 100,000, and our largest telescopes exhibit probably over 100,000,000.

327. The daily motion of the sky.—When you are out of doors in the evening, fix your attention on groups of stars near the horizon in the east and in the west. In about half an hour or an hour look again. The stars in the east are higher up in the sky; those in the west are lower down—perhaps out of sight. Some stars at the north, such as the Big Dipper, are always in sight,

but they are seen in different positions at different times. Watch the change in the position of the Dipper in an hour.

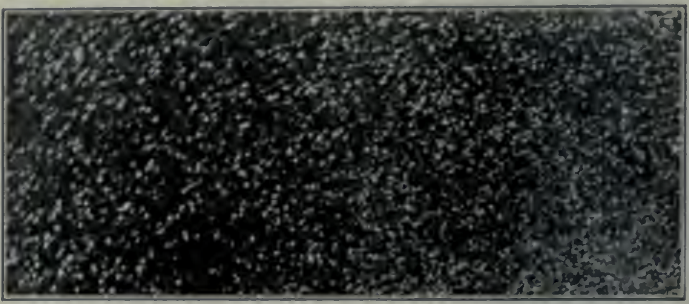
The stars thus seem to be in motion. A neat way to get evidence about this motion is given in Experiment 3. On developing the plate you will get a picture showing a large number of trails, each produced by a star, and they are all arcs of circles having a common centre. It is evident that there is no motion at this point, but that all the stars describe circles about it. It looks, then, as if the sky revolves on an axis which passes through the common centre of the circles, and as if it turns completely round this axis once in 24 hours.

Does the sky really turn after all? Is it possible that the sky, with all the stars on it, actually revolves about us once a day? We already know that there is a much simpler explanation, namely, that the earth turns, rotating on its axis once in 24 hours, but moving so gently that we do not perceive it.

328. The comparative brightness of the stars.—Stars are divided by astronomers into classes according to their brightness. The brightest are stars of the first magnitude, those somewhat less bright are of the second magnitude, and so on. The faintest stars visible to the unaided eye on a moonless night are of the sixth magnitude. The brightness of a star depends upon its size, its distance from the earth, and also upon the individual qualities of the star, for some are more luminous than others.

329. The distances of stars.—The distance from the earth of even the nearest of the stars is so great that it can scarcely be measured in miles, and it is found convenient to adopt as the *astronomical unit* of distance the mean distance from the earth to the sun (93,000,000 miles). The nearest star is more than 250,000 of these

units distant from the earth, some stars have been found to be 10,000,000 units distant, and it is probable that there are myriads of stars much farther away than any of those whose distance has been measured.



Courtesy of Yerkes Observatory
Fig. 176.—Stars in the Milky Way

Light travels at the rate of 186,000 miles per second, and, even at this high rate of speed, it takes four and one-third years for the light to travel from the nearest fixed star to the earth. There is little doubt that there are many stars so far removed from the earth that their light takes hundreds, and, in some cases, perhaps thousands of years to reach us. A conception of the distance of the stars may be gained from the fact that, although the volume of a star may exceed that of the sun, it always appears as a mere point of light even when viewed through the largest telescope.

330. The Milky Way.—The irregular band of light that can be traced in a northerly and southerly direction across the heavens is called the Milky Way or Galaxy (Fig. 176). The telescope shows that it is composed of an immense number of stars; in truth, by far the greater number of stars in the heavens are located in the Galaxy, and faint patches of light, scarcely discernible

by the naked eye, are broken up by the telescope into clusters of innumerable stars.

331. Nebulae.—There are many hazy, cloud-like masses in the heavens, called *nebulae*. Nebulae are of many sizes and shapes, some being spherical, others ring-like, others disk-shaped, while many are spiral. Nebulae also vary in composition. Some are shown by the spectroscope to be composed of gases. Others are not gaseous, and are believed to be composed of stars so far distant that they cannot be seen individually

332. The Ecliptic and the Zodiac.—Let an observer imagine that he is looking continuously from the earth toward the sun, while the earth is making its yearly journey in its orbit. The sun will appear to pass through a succession of constellations. The apparent path of the sun's centre through the heavens is called the *ecliptic*. Now imagine lines parallel to the ecliptic to be drawn on either side of it at a distance of 8°. The inclosed belt, or zone, is called the *zodiac* (Greek—*zodion*, an animal). The moon and the sun and the planets all appear to travel within this belt. Arranged along the ecliptic and largely within the zodiac are the following constellations—Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces.

333. Conspicuous constellations and stars.—The star maps, Figures 177, 178, represent a few of the brightest stars and most notable constellations in the heavens.

The Pole Star—Polaris—which can be located by following the guiding line from the "Pointers" of the Great Dipper, is a star of the second magnitude. It occupies a very important position, because it is now near to that part of the heavens toward which the earth's axis points. But the direction of the earth's axis is changing, and so Polaris is only a temporary Pole Star.

About 3,000 years ago the brightest star in the constellation of the Dragon was the Pole Star. Two hundred years from now the earth's axis will point more nearly toward Polaris than it does at present; but about 12,000 years

Fig. 177

Star map showing a few of the more important constellations and individual stars visible in the heavens in the positions indicated at the following times: Sept. 23rd at 9 p.m.; Oct. 10th, at 8 p.m.; Oct. 26th, at 7 p.m. To use the map hold it above the head, map surface downward and the end marked north turned toward the north. Locate the Great Bear (Ursa Major) and the Pole Star. By following the directions indicated by the dotted lines, find the constellations and the conspicuous stars that are named on the map. These individual stars may be recognized by their brightness, as they are more brilliant than any that are near them.

later the direction of the axis in space will have so changed that Vega will be the Pole Star. This brilliant star is approaching us at the rate of nearly 300 millions of miles a year, but its distance is so great that its approach at even this high velocity will cause no appreciable increase in its brightness in the next 12,000 years.

The stars of the winter skies present the most imposing spectacle (Fig. 178). The constellation Cassiopeia (The Woman in the Chair) is easy to recognize, the brighter stars composing it being arranged in the form of the letter W. Capella (The She Goat), and the three

near-by stars known as The Kids, lie slightly to the west of the line leading from the Dipper to the constellation Orion. The "sword and belt" of this mighty warrior may be easily distinguished.

There are two conspicuous objects in the constellation Taurus—the bright, red star, Aldebaran, and the group called The Pleiades. In the latter, six stars can be

Fig. 178.—Star map for Dec. 21st at 9 p.m.; Jan. 5th at 8 p.m.; and Jan. 20th at 7 p.m.

plainly seen, set in the form of a small dipper. It would seem that in ancient times a seventh star could easily be seen with the naked eye, as there are many references to the seven Pleiads in ancient literature. This group is the Seven Sisters of the Greeks, the Many Little Ones of the Babylonians, and the Seven Brothers of certain tribes of North American Indians. Besides those stars that can be seen with the naked eye, the group contains at least one hundred others which can be seen with a small telescope. When we reflect that many of the largest of the stars of this group that

occupies only a small space in the heavens are from one hundred to two hundred times as great in light-giving power as our sun, and that their distance from the earth can scarcely be less than 10,000,000 times that from the earth to the sun, we become bewildered in our efforts to comprehend the vastness of the universe.

CHAPTER XXIV

PROBLEMS ON THE RELATION BETWEEN PHYSICAL AND COMMERCIAL GEOGRAPHY

1. Why do the railways follow the rivers very closely in British Columbia and not in the Prairie Provinces? Compare the routes taken west of Winnipeg by the main lines of the Canadian National Railways and the Canadian Pacific Railway.

2. Why did waterways determine the location of early settlements in eastern Canada to a much greater extent than in the Prairie Provinces?

3. Why is the harbour of Prince Rupert open during the winter, while the harbours of Labrador in the same latitude are ice-bound?

4. Compare the distances to Liverpool from (*a*) New York, (*b*) St. John, (*c*) Halifax, (*d*) Montreal, (*e*) Port Nelson. What influence may these distances have on the development of trade routes across the Atlantic? Make a study of the advantages and disadvantages of the Hudson Bay route.

5. What are the chief factors that combine to produce a large seaport city? Use (*a*) London, (*b*) Montreal, (*c*) New York, to illustrate your answer.

6. Account for the unused natural harbours of British Columbia, western Scotland, and Norway.

7. What geographical factors have (*a*) retarded the exploration of Africa, (*b*) hindered the development of an extensive commerce in that continent?

8. Compare the plains of European Russia with those of western Canada with respect to (*a*) latitude, (*b*) elevation, (*c*) drainage, (*d*) climate, (*e*) industries, (*f*) products. Under normal conditions, to what extent and in what commodities does Canada trade with Russia?

9. List the manufactured products of your locality. Discover (*a*) the source of the raw materials used, (*b*) the market for the finished goods.

10. What are the chief natural products of the coastal regions of British Columbia, Norway, and southern Chile? Point out the geographical factors which account for (*a*) similarities, (*b*) differences in products.

11. Why is manufacturing developed more extensively in southern Ontario than in (*a*) the Maritime Provinces, (*b*) the Prairie Provinces?

12. On which side of Hawaii, of Australia, and of Japan is agriculture most extensively developed? Give reasons.

13. Explain why most of the cities of South America, except the seaports, are in the highlands within the tropics, and in the lowlands outside the tropics.

14. Why is irrigation necessary in southern California and in the regions surrounding the Mediterranean Sea?

15. Why has the basin of the La Plata-Parana River system developed much more rapidly than that of the Amazon?

16. Why in eastern Canada are logs floated down the rivers, whereas in British Columbia they are hauled by logging railways to the coast?

17. Why are the best wheat areas of England in the east, while the best grass-lands are in the west?

18. Why are mountain passes more valuable economically than mountain peaks? Illustrate by reference to the Rocky Mountains.

19. Why are the waterways north of Canada difficult to navigate, while those north of Europe are comparatively easy? Show the bearing of this on the development of seaports on the Arctic coast.

20. Why have the rivers comprising the St. Lawrence system so many rapids and falls, while those comprising the Mississippi system have so few? Compare these systems with respect to their value as sources of power. Why is the commerce of the St. Lawrence system so much greater than that of the Mississippi system?

21. The Laurentian Highland (sometimes called the "Canadian Shield"), though low and almost without mountains, produces many valuable minerals; the Alps mountains, the most massive in Europe, produce scarcely any. Account for this.

22. The rivers of Europe emptying into the Mediterranean Sea and the Black Sea have deltas, while those emptying into the Atlantic have not. Account for this, and show its bearing upon the location of the great seaports of Europe.

23. Why is the winter climate of St. John's, Newfoundland, milder than that of Toronto, although the latter city is about 300 miles farther south? What bearing has this on the commerce of these two cities?

24. Why are the trade routes in North America chiefly from east to west, while in Africa they are from north to south?

25. Java, with an area twice as great as the Maritime

Provinces, has a population of almost 40,000,000 people, and exports large quantities of food-stuffs; while the Amazon valley, although having a soil and climate similar to Java and being twenty times as large, is one of the most sparsely populated and commercially unimportant parts of the world. Account for this.

26. The chief cereals eaten by people within the tropics are rice, millet, and corn; in temperate regions, wheat and rye. Account for this.

27. State five economic uses of rivers. Illustrate these uses by reference to the following rivers—your local river, the Ottawa, the Mackenzie, the Saskatchewan, the Danube and the Nile.

28. The relative importance of the several economic uses of rivers depends largely upon the topography of the river basin. Discuss this, illustrating your answer by reference to the following Canadian rivers—the Trent, the Thames, the Niagara, the Fraser, and the Saskatchewan.

29. What geographical factors combine to produce the great grass-lands of Saskatchewan, the Orinoco Valley, Argentina, and Australia, respectively?

30. What geographical conditions cause Canada and Argentina to have similar agricultural products, for example, wheat, flax, cattle, and peaches? What differences in conditions in these countries make Argentina a market for Canadian lumber and farm machinery?

31. Why does Argentina ship beef to Britain while Canada ships cattle?

32. Name five estuaries of Europe and North America. How many of these give valuable aid to commerce? Make it clear why they do so.

33. What combination of geographical conditions has

made (a) Brazil the greatest coffee-producing country of the world, (b) the United States the greatest steel-producing country, (c) Great Britain the greatest trading country, (d) India the greatest rice-producing country, (e) Australia the greatest wool-producing country?

34. "The characteristics of the inhabitants are important elements in the development of the industries and commerce of a country." Discuss this statement, illustrating your answer by references to (a) wheat-growing in Canada and Russia, (b) the silk industry of France and Italy, (c) the woollen industry of Great Britain and the United States, (d) the dairy industry of Ireland and Denmark.

35. "The industrial habits of the people are, in turn, largely the result of geographical environment." Discuss this statement, illustrating from the industrial life of Norway, Holland, Czecho-Slovakia, and Arabia.

36. Name four industries that are characteristic of mountainous countries. To what extent is each due to the influence of physical conditions? Illlustrate by reference to (a) British Columbia, (b) Switzerland, (c) Peru.

37. Name four industries that are typical of plateau areas. Make clear the relation between each industry and the geographical conditions that have made it possible. Illustrate by reference to (a) the Interior Plateau of British Columbia, (b) Tibet, (c) South Africa.

38. "Australia has one of the largest and driest deserts in the world. It also has forests whose trees rival in size the giant sequoias of California." Describe in detail the geographical conditions that explain this apparent contradiction.

39. "When we compare the basin of the Mackenzie

River with certain lands, such as Finland and northern Russia, which are in the same latitude, we are led to conclude that it may yet support a population of eight millions." Find out whether the geographical conditions and other known facts justify such a conclusion.

40. Outline the geographical conditions that have favoured the development of (*a*) cotton-spinning in Manchester, (*b*) ship-building in Glasgow, (*c*) iron-manufacturing in Sydney, Cape Breton, (*d*) meat-packing in Chicago, (*e*) woollen-manufacturing in the cities of the New England States, (*f*) the manufacture of farm machinery in Toronto.

41. Mention at least five economic uses of lakes. Illustrate your answer by definite reference to the Great Lakes of North America.

42. By means of a trade-route map, trace two land routes of Europe or Asia. To what extent has the course of each been influenced by (*a*) mountain passes, (*b*) river valleys, (*c*) good harbours, (*d*) productive areas?

43. "Mountains have exerted a marked influence upon the distribution of the races of mankind." Discuss, using illustrations from Europe and Asia.

44. By the study of rainfall and temperature maps, find to what extent the Great Lakes modify the summer and winter climates of their locality. By referring to a map showing products, find to what extent the products of the areas surrounding the Great Lakes are due to these climatic influences.

45. Study a map showing the vegetation areas of Canada. Note the location of (*a*) hardwood forests, (*b*) Alpine coniferous trees, (*c*) northern coniferous trees, (*d*) prairies. What geographical conditions decide the location of each area? Account for the belts of

forest along the rivers far to the north of the main forests. Make a list of the wood products obtainable from each forest area.

46. By means of maps, find the distance saved by the Panama Canal route in preference to all other ocean routes between Hamburg and each of the following ports—(*a*) Vancouver, (*b*) Hong Kong, (*c*) Valparaiso, (*d*) Sydney, Australia. Consult statistics to learn (*a*) to what extent ships are making use of the Panama Canal, (*b*) to what extent the export trade of Canada passing through the port of Vancouver has been increased by the opening of this route.

47. What geographical conditions have caused London to become the world market for tea, wool, and ivory; New York, for coffee; and Liverpool, for wheat and cotton?

48. "All great manufacturing nations were originally great agricultural peoples." Examine the truth of this statement applied to such countries as Great Britain, Germany, Belgium, and the United States. Make clear the connection between agricultural production and the development of manufacturing.

"Although Egypt, China, Australia, Spain, and Mexico are great agricultural countries, they have not developed extensive manufactures." Why not?

49. Find the principal delta and flood-plain areas of North America and Asia. Give reasons why these areas produce large crops of cereals, cotton, or sugar-cane.

50. Make a study of the natural products of the Bahamas, the Bermudas, and the coral islands of the Pacific. Account for (*a*) the similarity, (*b*) the limited range of their products.

51. Among the causes of the growth of industrial

centres are (*a*) nearness to raw material, (*b*) nearness to markets, (*c*) power facilities, (*d*) favourable climate, (*e*) supply of labour, (*f*) the momentum of an early start, (*g*) transportation facilities. Show the way in which one or more of these causes have operated in the growth of each of the following—(*a*) Winnipeg, (*b*) Hamilton, (*c*) Montreal, (*d*) Pittsburgh, (*e*) Minneapolis, (*f*) St. Louis.

52. There are eight great wheat-producing areas in the world—central northern United States and western Canada, the Columbia Basin, the plains of southern Russia and of the Danube, north-western Europe, the Mediterranean countries, northwest India, southeast Australia, and Argentina. From a study of the climate of these areas, form conclusions as to suitable climatic conditions for wheat.

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